LIGHTING RESEARCH PROGRAM

Project 6.3: Codes and Standards Assessments

FINAL REPORT

Prepared For:

California Energy Commission

Public Interest Energy Research Program

Arnold Schwarzenegger, *Governor*

Consultant Report

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Executive Summary

The purpose of this report is to facilitate a discussion of each project's potential to influence the future development of efficiency standards.

A technology must have a track record in the market before being considered as a basis for code development. The product must demonstrate adequate and consistent energy savings, be readily available in the market, and be non-proprietary in nature in order to be considered for a code revision. Since most of the LRP projects are in the final design stages, or in early marketing stages, they need more promotional efforts to establish market presence before any code revisions can be undertaken. Utility incentives are a good way to establish market presence.

This report therefore considers the prospects for the adoption of the LRP technologies into an incentive program run by California utilities. Four factors are analyzed:

- Opportunity for Code Improvement
- Total Resource Cost Ratio
- Peak Demand Reduction Cost
- Strategic Benefits

Most of the LRP projects were designed to cost-effectively reduce energy consumption, but the cost estimates show that several of them would be cost-effective in reducing peak electrical demand as well (in the case of demand reduction, cost-effectiveness can be judged relative to existing sources of demand reduction).

Technologies that reduce electrical load at times of peak demand, for instance daylight-linked lighting controls, are particularly valuable because they simultaneously reduce both energy consumption and peak demand.

It should be borne in mind that the results of the Total Resource Cost calculations (as discussed below) are based on the assumption that the electricity consumption of each technology follows the general shape of the electrical demand curve. This means that technologies that reduce peak demand are undervalued, and those that primarily reduce load at non-peak times may be overvalued by TRC.

Figure 1 – Summary of the merits of each project for adoption into utility incentive schemes; an asterisk indicates a strong reason for inclusion in a utility incentive program

Project #, Project Name		Opportunity for Code Improvement	Total Resource Cost Ratio	Peak Demand Reduction Cost	Strategic Benefits
2.1	LED Exterior Lighting	*	Not calculated	Not calculated	*
2.2	LED Task Lighting		Not calculated	Not calculated	
2.3	LED Low Profile Lighting		Not calculated	Not calculated	
3.1	Retrofit Fluorescent Dimming	*	Not calculated	Not calculated	*
3.2	Load shedding Ballast	*	Not calculated	*	
3.3	Classroom Photosensor	*		*	*
4.1	Hotel Bathroom Lighting	*			*
4.2	ENERGY STAR® Residential Fixtures	*	Not calculated	Not calculated	*
4.3	Retrofit Energy Efficient Downlights	*	*	*	
4.4	Portable Workstation Lighting		Not calculated	Not calculated	*
4.5	Integrated Classroom Lighting	*			*
5.1	Bi-level Stairwell Fixtures	*	*		
5.2	HID Electronic Ballast testing	*	Not calculated	Not calculated	
5.3	Low Glare Outdoor Lighting		Not calculated	Not calculated	*
5.4	DALI		Not calculated	Not calculated	

Figure 2 - Rating system used in Figure 1

Rating	Opportunity for Code Improvement	Total Resource Cost Ratio	Peak Demand Reduction	Strategic Benefits
*	Near-term, opportunity for code change (see Summary below)	TRC ratio > 1	Prospect for > 1 MW at a cost <$200/kW	Significant strategic benefit
	Long-term opportunity, or no opportunity for code change	TRC ratio < 1	No significant prospect	No strategic benefit, or limited benefit

Definition of Terms

Opportunity for Code Improvement

Technologies and design approaches can form the basis for improvements in the mandatory and prescriptive efficiency standards demanded by Title 24 and other voluntary standards such as LEED, CHPS and Energy Star. To be considered as part of an argument in favor of a standards improvement, a technology must achieve a certain level of success in the open market, and must demonstrate verifiable and repeated energy savings at a reasonable cost.

Because the technologies in the LRP portfolio have, by their nature, not yet been successful in the open market, they cannot yet be considered ready to influence standards. A few of the projects seem set to achieve market success, but the lighting market is highly unpredictable due to the influence of factors such as aesthetics, ergonomics, multiple alternative uses for the same technology, and architectural co-ordination that do not affect other building technologies to the same degree.

In this report the projects have been divided up into those with "near-term" potential (i.e., they could be considered for the 2008/2011 edition(s) of Title 24, or for other voluntary standards that will be written during the next 2-5 years), and those with "long-term" potential. This distinction is subjective, but is based on market readiness and goodness-of-fit with the structure of existing codes and standards.

Total Resource Cost Ratio

Net costs have been calculated using the California Public Utilities Commission (CPUC) Total Resource Cost (TRC) method. This method seeks to quantify the net energy cost (to society as a whole) of installing energy-saving measures. The outcome variable is the TRC Ratio, which is the total benefit divided by the total cost, irrespective of who receives the benefits and who pays the costs.

TRC has been used because the most immediate development path for the LRP technologies is to be adopted into an incentive program run by California utilities, and these incentive programs are overseen by the CPUC, which uses the TRC method to evaluate net cost. The TRC evaluates only the annual energy saving, and does not yet include a method for evaluating peak load reduction – this is planned for 2005.

It should be remembered that the "benefit" side of the TRC equation only takes into account the financial value of the energy saved, it does not attempt to quantify the value of other environmental and societal benefits that arise either from the technology itself or from the energy saved.

California Energy Commission Cost effectiveness criterion for Title 24

If the LRP projects are to be used as support for future proposals for changes to the Title 24 energy efficiency standards, they will have to pass the California Energy Commission

(CEC) Net Cost tests. The CEC's tests are slightly different method to the CPUC's, yet sufficiently similar that the results under one test are highly indicative of results under the other. The CEC is required by law to develop and maintain energy efficiency standards that are "*cost effective, when taken in their entirety, and when amortized over the economic life of the structure when compared with historic practice*"[1]. More information on the principles of life-cycle costing used by the CEC can be found on their website[2]. The CEC currently uses a criterion called "Annual Life-Cycle Cost", in which the net present value (NPV) of the savings is calculated by multiplying the annual savings by the present value of a unit of saved energy. This method is very similar to the CPUC's Total Resource Cost.

Peak Demand Reduction Cost

Because the TRC method does not include peak demand reduction, we have quantified the demand reduction that is expected to result from each of the technologies, and have expressed it in $/W, i.e. the cost of reducing summer peak demand by one Watt. The magnitude of these values is discussed later in this report.

Peak Demand Reduction Requirements for Title 24

The CEC uses Time-Dependent-Valuation (TDV) to estimate the costs avoided by technologies that include a significant element of peak demand reduction. This is a more advanced approach than annual LCC. Under this method it is necessary to estimate energy savings on an hourly basis. The energy savings for each hour are multiplied times the net present value of energy for that hour. The CPUC does not currently have an equivalent to this calculation method.

Strategic Benefits

The Commission's legal requirement for cost-effectiveness cited above applies to the standards as a whole, rather than to each individual measure. This gives the Commission some latitude to support technologies that may not be themselves cost-effective, but serve to support other technologies, or to advance the market, or to prepare the ground for future change. For this reason, this report sets out some of the strategic issues that surround each of the LRP projects.

[1] Warren Alquist Act, Section 25402.

[2] California Energy Commission, *Life Cycle Cost Methodology, California 2005 Building Energy Efficiency Standards*. Submitted by Eley Associates under contract number 400-00-061, P400-02-009, March 2002

Summary

Opportunity for Code Improvement

The following table provides a snapshot of the code potential analysis conducted. Details on each of the projects and the nature of code opportunities and barriers are provided in the subsequent sections of this report.

Figure 3 - Code Opportunity Summary

Project #, Project Name		Term	Relevant Codes/ Standards	Market Readiness
2.1	LED Exterior Lighting	**Near-term**	Title 24	**Market Ready Soon**
2.2	LED Task Lighting	Long-term	Title 24	Under Development
2.3	LED Low Profile Lighting	Long-term	Title 24	Under Development
3.1	Retrofit Fluorescent Dimming	Long-term	Title 24, CHPS	Under Development
3.2	Load shedding Ballast	Long-term	Title 24, CHPS	Under Development
3.3	Classroom Photosensor	**Near-term**	Title 24, Title 20, NEMA, CHPS	**Market Ready Soon**
4.1	Hotel Bathroom Lighting	**Near-term**	Title 24	**Market Ready**
4.2	ENERGY STAR® Residential Fixtures	**Near-term**	Title 24, Energy Star	**Market Ready Soon**
4.3	Retrofit Energy Efficient Downlights	**Near-term**	Title 24, Title 20, Energy Star	**Market Ready**
4.4	Portable Workstation Lighting	Long-term	Title 24	Under Development
4.5	Integrated Classroom Lighting	**Near-term**	Title 24, Dept. of State Architect, LEED, CHPS	**Market Ready**
5.1	Bi-level Stairwell Fixtures	**Near-term**	Title 24, ANSI	**Market Ready**
5.2	HID Electronic Ballast testing	**Near-term**	Title 20	N/A
5.3	Low Glare Outdoor Lighting	Long-term	Title 24, IESNA	Under Development
5.4	DALI	Long-term	Title 20, NEMA	Under Development

Total Resource Cost Ratio

For energy-efficiency measures, the Total Resource Cost (TRC) ratio provides an indication of whether the measure will result in a net financial expenditure or a net financial saving for society. TRC ratios less than one indicate a net expenditure, ratios greater than one indicate a net saving.

This section describes TRC calculations performed for five of the PIER LRP projects:

- 3.3 Classroom Photocell System
- 4.1: Hotel and Institutional Bathroom Lighting Project
  - The analysis is conducted for the wall switch nightlight only. The project team is also developing a fixture integrated nightlight that is expected to have greater savings due to reduction in installed wattage.
- 4.3: Energy-Efficient Retrofit/Remodel Alternative to Incandescent Downlights
- 4.5: Integrated Classroom Lighting System
- 5.1: Bi-Level Stairwell Fixture Performance

Figure 4 shows the TRC ratio for each project, along with a projection of what each project's incremental measure cost would have to be, to make the TRC ratio equal to one.

<table>
<tr><th>Project number</th><th colspan="3">Project Title</th><th>TRC Ratio</th><th>Incremental Measure Cost</th><th>Incremental measure cost required to make TRC=1</th></tr>
<tr><td>3.3</td><td colspan="3">Classroom Photocell</td><td>0.78</td><td>$719</td><td>$553</td></tr>
<tr><td rowspan="2">4.1</td><td colspan="3">Hotel Bathroom Lighting
(“business hotel”)</td><td>0.32</td><td>$65</td><td>$21</td></tr>
<tr><td colspan="3">Hotel Bathroom Lighting
(“vacation hotel”)</td><td>0.82</td><td>$65</td><td>$53</td></tr>
<tr><td>4.3</td><td colspan="3">CFL Downlights for Kitchens</td><td>4.22</td><td>$10</td><td>N/A</td></tr>
<tr><td rowspan="5">4.5</td><td rowspan="5">Classroom Lighting</td><td>Scenario A</td><td>2-row switching, estimate from case study</td><td>0.66</td><td>$619</td><td>$409</td></tr>
<tr><td>Scenario B</td><td>2-row dimming, estimate from case study</td><td>0.48</td><td>$994</td><td>$477</td></tr>
<tr><td>Scenario C</td><td>3-row switching, estimate from case study</td><td>0.30</td><td>$1719</td><td>$516</td></tr>
<tr><td>Scenario D</td><td>3-row dimming, estimate from case study</td><td>0.23</td><td>$2219</td><td>$510</td></tr>
<tr><td>Scenario E</td><td>2-row switching, energy saving estimate based on bi-level switching study</td><td>0.30</td><td>$619</td><td>$186</td></tr>
<tr><td>5.1</td><td colspan="3">Bi-level fixture</td><td>1.06</td><td>$277</td><td>N/A</td></tr>
</table>

Figure 4 – TRC ratios and cost reduction requirements

The calculations of TRC ratio in this report do not include the administrative and overhead costs required to run the programs. These can typically be as high as 30% of the program cost. Thus a product would typically need a TRC ratio of at least 1.30 in order to cost effective in a utility program.

Figure 5 summarizes the process used to calculate TRC ratios. For each project, only one sample calculation is shown – the others follow the same format but with different values. The letters in parentheses describe how each value is calculated from previous values. More information about how each value was derived can be found in the following sections.

The only values used in the calculation of TRC ratio are:

- Gross annual energy savings (positive effect)
- Gross incremental measure cost (negative effect)
- Expected useful life (positive effect)
- Present value of annualized savings per kWh (calculated from expected useful life)

From the list above, it can be seen that the calculation of TRC ratio does not include a value for expected peak demand reduction, and that the ratio is based only on annual savings estimates. However, the value of annualized savings per kWh is based on an average of both on-peak and off-peak costs, so for technologies where the on-peak load is similar to the off-peak load, the effect of peak demand reduction is factored in correctly. Conversely, technologies that save more load at peak time than at other times will be undervalued in the TRC calculation, and technologies that save less load at peak time than at other times will be overvalued.

The CPUC is currently in the process of adopting a more detailed set of calculations to value programs based on their peak savings, but this won't be available until 2005.

Project Number		3.3	4.1	4.3	4.5	5.1
Project Title		Classroom Photocell	Hotel Bathroom Lighting††	CFL Downlight	Classroom Lighting†††	Bi-level fixture
Unit Goal	(a)	800	770	20000	1600	3000
Unit Definition		one classroom	one fixture	one downlight head	one classroom	one fixture
Installation, Service, and Repair Labor Costs		0	0	0	0	0
Gross Annual Energy Savings (kWh)	(b)	773	50	59	258	392
Gross Incremental Measure Cost	(c)	$719	$35	$10	$619	$264
Expected Useful Life (years)	(d)	16	8	16	16	16
Net-to-Gross Ratio	(e)	0.8	0.8	0.8	0.8	0.8
Total Gross Incremental Measure Cost	(f=a*c)	$575,200	$26,950	$200,000	$990,400	$792,000
Total Net Incremental Measure Cost	(g=f*e)	$460,160	$21,560	$160,000	$792,320	$633,600
Projected Annual Net Energy Savings (MWh)	(h=a*b*e)	495	31	944	330	941
Projected Lifecycle Net Energy Savings (MWh)	(i=h*d)	7916	246	15104	5284	15053
Present Value of Annualized Savings per kWh	(j†)	0.72	0.42	0.72	0.72	0.72
Net Electricity Benefits	(k=h*j)	$354,209	$12,959	$675,885	$236,445	$673,593
TRC ratio	(l=k/g	**0.77**	**0.6**	**4.22**	**0.30**	**1.06**

† average present value of all kWh to be saved over the EUL of the measure. Assuming a discount rate of 8.15%

†† Business hotels, new rooms

††† 2 row switching system, energy savings estimated from bi-level study

Figure 5 – Sample TRC ratio calculations

Peak Demand Reduction Costs

Peak demand reduction is an increasingly important component of California's energy infrastructure, although it remains difficult to quantify the financial benefit of reducing peak demand, and the market for peak demand savings is not yet well established.

For this report, we have simply calculated the expected cost of achieving a Watt of peak demand reduction using each of the LRP technologies, amortizing the cost of each technology over its expected useful life. Only one of the technologies is specifically aimed at demand reduction, but several of them substantially reduce demand as a side-effect of reducing energy consumption; this is particularly true of technologies that reduce light levels in response to daylight.

Lighting – HVAC Interaction

It should be noted that in these calculations the "raw" estimates for annual energy savings and peak demand reduction are both modified by a factor that takes into account the interaction between lighting and HVAC systems. When lights are switched off, cooling energy is usually saved because the heat generated by the lights does not have to be removed from the building by the air conditioning system. The amount of additional energy saved varies depending on the climate and on the efficiency of the air conditioning system. For California, the additional savings average around 18% of the lighting energy savings (assuming a "lighting-to-cooling fraction" of 0.5[i] and a coefficient of performance for the air conditioning system of 2.5. The figure for 2.5 COP is calculated from the Federal standard[ii] for 8.5 EER and a conversion factor of 0.293).

An 18% adjustment for "lighting-HVAC interaction" has therefore been made to the figures for both annual energy savings and the peak demand reduction for each of the LRP lighting technologies, except for the bi-level stairwell fixture and the hotel bathroom nightlight fixture, in which the energy savings are generally achieved overnight when there is no cooling load.

Cost of Peak Demand Reduction

The estimates in Figure 6 can be compared with values for the cost of electrical load shedding given in a report from the Peak Load Management Association (Peak LMA)[iii]. The Peak LMA report found that the average cost of load shedding in dedicated load shedding programs was $85/W, which is not dissimilar to some of the values shown below. This indicates that, in addition to project 3.2 (load shed ballast), projects 3.3 (classroom photosensor) and 4.3 (residential retrofit fixture) could be viewed by utilities as passive load-shedding programs, comparable in cost to managed load-shedding programs. These "passive" programs would reduce the "peak" of the demand curve, and would have lower overhead costs than managed programs, but could not be relied upon to shed a known amount of load at a specific time.

The maximum cost reported by the Peak LMA was $878, which indicates that the LRP technologies may be a lot more cost-effective than the least cost-effective parts of existing utility load-shedding portfolios.

It should be noted that no interest rate has been applied to the capital cost of the measures shown in Figure 6.

Figure 6 – Peak Demand Reduction Costs

Project Number		**3.2**	**3.3**	**4.1**	**4.3**	**4.5**	**5.1**
Project Title		Load-shed ballast	Classroom Photocell	Hotel Bathroom Lighting†	CFL Downlight	Classroom Lighting††	Bi-level fixture
Gross Incremental Measure Cost	(a)	-	$719	$65	$10	$619	$277
Projected Net Coincident Peak Demand Reduction (W)	(b)	-	295	12.8	7.6	18	Data not available
Expected Useful Life (years)	(c)	-	16	8	16	16	16
Peak Demand Reduction ($/kW)	(d=a/b/c)	**$94**[a]	**$152**	**$635**	**$82**	**$2,149**	-

[a] See Deliverable 6.3.4: Complementary Research Review

† Business hotels

†† 2 row switching system, energy savings estimated from bi-level study

Detailed Report

Following is a brief discussion on each of the PIER LRP products for the following two criteria:

- Opportunity for Code Improvement – In this section we identify the barriers to compliance with existing codes and standards provisions, opportunities to use current code provisions for increasing market penetration of the products, as well as opportunities for improving current codes and standards based on the LRP product capabilities.
- Strategic Benefits - In this section we identify possible additional benefits that go beyond the energy savings achieved by each technology in its intended application. In some cases the definition of strategic is problematic; for instance the DALI Protocol is intended for a wide variety of applications and is therefore inherently strategic. The Portable Workstation Lighting fixture is intended for a market that does not yet exist and may not ever exist unless the initiative is taken to create it, and for that reason we have classified it as a strategic product. In other cases, such as the Retrofit Energy-Efficient Downlight, the product could create a widespread reduction in energy use in its target market, but since this is usually the expectation inherent in an incentive program, we have not classified this project as strategic.

2.1 LED Exterior Lighting

Opportunity for Code Improvement

Nonresidential, high-rise residential and hotel/motel exterior, porch, and perimeter lighting is covered by the 2005 California Title 24 energy standards. Permanently installed luminaires must either be high efficacy (i.e., lamp efficacy of at least 60 lumens per watt for luminaires 100W or more), or be controlled by motion control devices. In addition all permanently installed outdoor lighting is required to be controlled by photocontrol or astronomical time switch that automatically turns off the outdoor lighting when daylight is available.

Residential outdoor lighting must use high efficacy light sources (40 lumens per watt for lamps 15 Watts or less) or be controlled with a motion sensor with integral photosensor.

Since the efficacy of LEDs is currently less than 40 lm/W, LED light fixtures without occupancy sensors with integral photosensor currently do not qualify for the outdoor lighting requirements. Even with the integral occupancy and photosensor, the product faces one additional hurdle to compliance with Title 24 – the always ON feature of the LED amounts to an always-on standby load for the light fixture. Title 24 stipulates that all non-high efficacy fixtures must be completely shut OFF during times of non-occupancy. An exception for LED 'stand-by' lighting may be sought in the future code revision cycle.

However, the efficacy of LEDs is constantly improving, and they might qualify as high-efficacy sources in the years to come.

In order to control glare, light trespass and sky glow, nonresidential outdoor lighting must use luminaires that are designated as "cutoff" (i.e. they do not emit light above horizontal) when the installed wattage per lamp is above 175 watts. However, there is currently no requirement for residential outdoor lighting to meet this cutoff standard. Currently, cutoff would be difficult to achieve because most residential outdoor lighting uses CFLs, which are not photometrically suited to achieving cutoff designation without compromising efficiency and uniformity of illuminance. Conversely, LEDs are small point sources and can easily be controlled to meet cutoff requirements without significant loss of efficiency, and while preserving uniformity. Therefore, if a future revision of Title 24 were to require residential lighting to meet the same cutoff requirements as nonresidential lighting, an existing market for LED fixtures would be beneficial.

Strategic Benefits

No research has been conducted to find out what performance features homeowners want from outdoor luminaires, and how these luminaires are used in practice. A monitored field trial of installed systems might suggest ways in which outdoor luminaire designs could be improved, or ways in which they could more efficiently be regulated while preserving the essential performance features the homeowners value. This knowledge could lead to a significant reduction in residential outdoor lighting use, and so is strategically important.

2.2 LED Task Lighting

Opportunity for Code Improvement

Task lighting is not currently covered by the California Title 24 standards for either residential or non-residential buildings. The 2001 California Title 20 Appliance Standards have wattage restrictions for torchiere fixtures, placing a lamp wattage limitation of no more than 190 watts on one fixture. Fixtures below 190W are currently not covered by either standard.

Based on the improving efficacy, color properties and safety features of LEDs, changes could be proposed to future round of changes to the Title 20 appliance standards to include efficiency requirements (lumens/watt or total wattage per lamp) for task light fixtures.

Strategic Benefits

Although the current rate of development of LEDs and LED fixtures is extremely rapid, at this stage we see no clear strategic benefits arising from this technology. LEDs do seem to offer two possible benefits over the CFL lamps currently used in high-efficacy task lights – small size, and controlled beam spread. However, the issue of heat dissipation is critical to making this technology work for task lighting, both for energy efficiency and safety in use.

2.3 LED Low Profile Lighting

Opportunity for Code Improvement

The low profile fixture developed within this project was intended for use in elevators. Elevator lighting is not currently given specific treatment in Title 24, but it is included in the “planned lighting” of the space, so it contributes toward the total lighting power density calculation. Since elevator lighting is such a small component of the lighting of a building (2% is the figure estimated by the project team) that it seems unlikely to be considered specifically in future revisions of the standard, so we don’t anticipate this project to have a significant impact in the context of future code development.

The low-profile fixture could be used in other applications, but these have not yet been identified.

Strategic Benefits

As above, although the current rate of development of LEDs and LED fixtures is extremely rapid, at this stage we see no clear strategic benefits arising from this technology

3.1 Retrofit Fluorescent Dimming

Opportunity for Code Improvement

Title 24 currently provides Power Adjustment Factor credits for dimming ballasts that encourage the use of fluorescent dimming in various spaces. Since this product is designed for retrofit application, it is not currently governed by the Title 24 energy codes in California, which deal mostly with new construction. The only exception is when over 50% of the luminaries are replaced, the lighting needs to comply with the Title 24 code requirements. The nature of retrofit required for installing the retrofit fluorescent dimming system would not trigger this code requirement.

A code change proposal that includes comprehensive efficiency requirements for retrofits and existing buildings is currently being discussed, but will not be in place before 2008. Utility incentives to support the early adoption of this technology would advance the prospects for treatment of existing buildings in future revisions of Title 24.

Strategic Benefits

This project is by its nature strategic, because it facilitates energy savings across a wide variety of applications, and enables better use of existing energy-saving resources.

3.2 Load shedding Ballast

Opportunity for Code Improvement

For new construction applications, the 2005 California Title 24 (Table 146-A) provides a power adjustment factor (control credit) of 0.25 for using *manual dimming with automatic load control of dimmable electronic ballasts*. These credits are not mandatory in nature and only serve to provide an incentive to use a technology that does not have the desired market penetration for a mandatory standard. For retrofit applications, the same credit can be taken when retrofitting more than 50 percent of the lighting system (light fixtures), which would trigger a requirement for code compliance with the latest standards. This requirement for code compliance is only triggered if the whole fixture, rather than just the ballast, is being replaced.

However, the ballast defined in project 3.2 is not a dimming ballast but a switching ballast, and is not designed to be manually controlled by occupants (though, incidentally, this feature could easily be provided, and would make the ballast compliant with the multi-level switching requirements of Title 24 2005 §131(b)).

Within table 146-A, the power adjustment factor for "load control" could be expanded to cover non-dimming ballasts. It should be noted that load shedding may be redundant in spaces that have automatic daylight controls.

Alternatively, if pilot installations show that lighting load shedding is cheap and unobtrusive, it could be considered as a mandatory measure in, for instance, office and warehouse lighting in future revisions of Title 24.

Strategic Benefits

Load shedding is a priority for the California utilities and the California Energy Commission, both of whom anticipate increasing peak loads over the coming years. Load shedding is critical to the health of the California electricity market, and as such this product is strategic. If this technology is proven to be cost-effective and shows consistent savings, it could be included in the suite of tools used by the utilities to achieve load shedding.

3.3 Classroom Photosensor

Opportunity for Code Improvement

The specifications of the photocell have the potential for inclusion in the "Acceptance Testing Requirements" for approved controls in future versions of Title 24, *if it is accepted by the controls industry as an industry wide standard*. This industry wide acceptance could come in the form of standards by national associations and standards-setting bodies, or through an industry group set up for this specific purpose that results in commitments from various manufacturers to implement the product specifications in their product lines.

The product itself already enjoys daylighting control credits in the existing code language and together with the bi-level control-enabled occupancy sensor benefits from the bi-level control credit in the 2005 Title 24 code (Table 146-A). In this case the code provision is in advance of verified energy savings, since no large field trials have yet been conducted to measure the effectiveness of daylighting control in sidelit spaces in California. Following the results of such a study, it may be justifiable to change the value of the control credit, or in certain spaces to mandate the use of daylighting control.

The most innovative features of the photosensor system are the "desktop commissioning tool" and the "sliding setpoint" control algorithm. Both these features are new to the US market and are potentially important developments. However, success of the system depends largely on the acceptance of the commissioning protocol by various manufacturers and in-turn designers and users of the spaces that this product is targeting. It would be worthwhile to incorporate the commissioning protocols in various commissioning standards that are taking shape in California and elsewhere in the US.

The product may also benefit if the CHPS program finds the system cost effective and beneficial for schools.

Strategic Benefits

The Classroom Photosensor uses an innovative "sliding setpoint" control system designed to make the operation of the system less obvious and less visually intrusive, and thereby to improve occupant acceptance of daylight-linked systems. This is an important strategic goal because sliding setpoint systems could also be used in offices and other daylit spaces.

As part of this project, computer simulations of the visual conditions in classrooms have been run, and have shown that the photosensor maintains a fairly constant illuminance on the working plane. Another important strategic goal in the development of daylight-linked control systems is to find out whether maintaining a certain value of desktop illuminance is a good idea for a control system, or whether some other method would better suit the classroom environment, and further improve the acceptance of systems. Monitoring of installed systems would bring this strategic goal within reach.

The classroom photosensor system is designed to work with dimming ballasts. An increased market for dimming ballasts is desirable from a strategic point of view, since this will improve the understanding of dimming technologies among electrical contractors, lighting reps and specifiers, and may help to standardize products.

4.1 Hotel Bathroom Lighting

Opportunity for Code Improvement

Hotel and motel guestrooms are currently excepted from the nonresidential requirements of Title 24 (2005), and are treated the same as residential buildings. This means that they are required to have either high efficacy lamps, or occupancy-sensor controls, but not both. Most new-build hotel and motel bathrooms use high efficacy lamps already, and no control credit is available for owners who install this new product.

The other code related issue with the product is the always ON feature of the LED during periods of non-occupancy. Since, the code stipulates that the source be either high-efficacy or be OFF during time of non-occupancy, the motion sensor night-light would not qualify with the existing 2001 or the upcoming 2005 Title 24 standards. A definition of 'stand-by' lighting load may be introduced in future revisions of the standard to account for a low level always-on lighting for way finding or night-light.

To encourage the adoption of not only this product, but of other lighting controls more widely, the current exception for hotel and motel guestrooms in Title 24 could be removed in future revisions. Trials of the acceptance of lighting control system in guestrooms are an essential precursor to any revision.

Strategic Benefits

The occupancy sensor used in the wall switch version of this device is very similar to occupancy sensors sold in the residential market. Successful introduction of this device in hotels and motels would familiarize a lot of people with this technology, and might encourage them to use occupancy sensors in their own homes.

4.2 ENERGY STARÒ Residential Fixtures

Opportunity for Code Improvement

These light fixtures are considered to be task lighting or portable lighting, so they are not currently governed by Title 24 for residential applications. Section 1605.3(n) of the 2001 California Title 20 Appliance Standards has wattage restrictions for torchiere fixtures, limiting lamp wattages to a maximum of 190 watts on one fixture. Light fixtures of less than 190W are currently not covered by the standard.

However, if the products demonstrate considerable savings and acceptance by purchasers, there is a possibility of proposing new efficiency requirements for task lighting in residential applications in the Title 20 standards. Utility rebates might be the best way to ensure that enough fixtures are bought to form a basis for field verification.

Finally, these products are anticipated to have ENERGY STAR® certification.

Currently, there is one major difference in the Title 24 specifications and ENERGY STAR® in that ENERGY STAR® does not require electronic ballasts while Title 24 standards require electronic ballasts for all high-efficacy hard-wired fixtures. However, ENERGY STAR® is actively considering incorporating the electronic ballast in its specifications, which would make it easy for ENERGY STAR® products to qualify as Title 24 compliant fixtures for hardwired lighting. Any future recommendations for inclusion of task lighting in Title 24 or Title 20 is bound to include requirements for electronic ballasts, so this is an important criterion for the LRP product development.

Strategic Benefits

The residential light fixture market is dominated by fixtures with traditional styling that were originally designed for incandescent lamps and are not well suited to CFLs or linear fluorescent lamps. To support the increased use of high efficacy lamps in the residential market, it would be useful to encourage fixtures such as those developed in the LRP project, which either use modern styling, or use traditional styling that has been adapted for high-efficacy lamps.

The Complementary Research Review (deliverable 6.3.4) cites evidence that task lights are prevalent in US homes, and make up a significant amount of residential lighting energy use, which makes the support of high efficacy task lighting an important strategic goal.

4.3 Retrofit Energy Efficient Downlights

Opportunity for Code Improvement

Exception 150(k)2 to 2005 Title 24 allows up to 50% of the lighting in residential kitchens to be non-high efficacy. CFL-based kitchen downlight are becoming widespread in California, and this holds out the possibility that in future revisions of Title 24, this exception could be removed. Currently, fluorescent fixtures are the only viable way of achieving high efficacy lighting in residences; questions remain, however, over whether the color rendering of CFLs and linear fluorescent lamps is sufficiently good to mandate their use as the only light source in kitchens. The adoption of high efficiency lighting in kitchens is proceeding quickly, and the Retrofit Energy Efficient Downlight is one such product currently being marketed and 'test-driven' by builders. Along with similar efforts by DOE and other agencies, this has the potential of affecting future energy standards for residential lighting.

Strategic Benefits

The main feature of this product that differentiates it from other CFL downlight fixtures is its remote and multi-lamp ballast. The ballast along with the master-slave configuration of fixtures generates savings in installation costs and time, which in turn results in a greater benefit/cost ratio for this product compared to other CFL downlights.

4.4 Portable Workstation Lighting

Opportunity for Code Improvement

Portable lighting is potentially a much more efficient way to light an office than the current practice of general lighting from ceiling-mounted fixtures. However, portable lighting is currently not governed by the Title 24 or Title 20 standards. However, Title 24 does acknowledge task lighting in the prescriptive requirements of the 2005 revision of Title 24, which state that if the wattage of task lighting is not known at design time, the lighting power density calculation should assume 0.2W of portable lighting power (section 146(b)). This would potentially give advantage to a task-ambient lighting system which would not be required to use the additional 0.2W for portable lighting in their installed LPD calculations. To get compliance for such a task-ambient system, the lighting designer needs to submit adequate supporting document to indicate the installed wattage for ambient and task lighting separately, and using their combined total LPD as the designed LPD for the space. This combined LPD is anticipated to be lower than the LPD from traditional ceiling mounted lighting.

An alternative approach might be to allow a Power Adjustment Factor ("control credit") for lighting that can be controlled from the workstation. Many studies have found that people who are given more control over their lighting tend to use it less, so such an addition to the control credits would be justified prima facae on the basis of research, but would require field verification before being adopted into code.

A more radical approach in the longer term would be to reduce allowable lighting power densities to the point where ceiling lighting would no longer be able to guarantee sufficient workstation illuminance at every point in the room.

Strategic Benefits

The section above on "Opportunity for Code Improvement" describes the strategic advantage of encouraging task-based rather than general lighting.

4.5 Integrated Classroom Lighting

Opportunity for Code Improvement

One of the most important innovations of this project is the use of fixtures that are pre-wired for occupancy sensors; this greatly speeds up installation time on site, and reduces the possibility of wiring mistakes. If field trials show that this system is a significant benefit, a requirement or a credit for pre-wired lighting controls in continuous-row suspended light fixtures could be incorporated into the Collaborative for High Performance Schools guidelines.

Another aspect of this system relevant to code is the high percentage of uplight in the space. The view of the project team, and of many lighting researchers, is that uplight allows the same impression of "lightness" to be created with a lower lighting power density, since uplight reduces the impression of gloom, and provides better lighting of faces and walls. Pending successful field monitoring, future revisions of Title 24 could reduce the allowable lighting power density for schools, and encourage the use of a certain percentage of uplight.

A final innovative feature is the streamlined process for specification, ordering and delivery. To some degree, streamlined procedures are a standard feature in the lighting industry – for instance, when ordering a luminaire it's not necessary to specify that it include a lampholder and a mounting kit, those things are "boxed" with the fixture. However, the Integrated Classroom Lighting System takes this idea to a further level by allowing specifiers to order the fixtures and the controls in the same package. This speeds up the design process since the designer knows for sure that the wires will be routed correctly inside the fixtures, and will physically fit inside the fixture housing without causing physical or electrical interference. There are benefits for the electrical contractor too, since the system arrives on site in one box rather than several, and the contractor has a single point of contact in case of questions, errors or complaints. It is possible that this streamlined process could be given credit within the CHPS or Acceptance Testing requirements.

The Technology Transfer Plan alludes to potential of getting the integrated lighting system approved and encouraged through the California Department of the State Architect. The DSA is currently looking into the code implications for lighting in classrooms (both traditional as well as re-locatable), and there could be greater market penetration of the lighting system if the DSA is on board in the marketing strategy.

The product specifications (including, for instance, the integrated wiring system and its connections) need to be non-proprietary in nature in order to make the specifications industry-accepted standards and for possible inclusion in the acceptance testing requirements. The approach, as mentioned in the TTP, of doing more long-term demonstration projects and some pilot installations would help in further identifying the system costs as well as performance issues.

Strategic Benefits

The section above on “Opportunity for Code Improvement” lists several strategic benefits, all of which could be supported in future revisions to energy efficiency standards.

5.1 Bi-level Stairwell Fixtures

Opportunity for Code Improvement

The latest ANSI standard (ANSI 117.1 to be published in the next ANSI 101 life safety code) offers both a barrier to energy conservation goals as well as a new window of opportunity for the bi-level stairwell fixture product.

The new standards increase the minimum light levels in stairwells from one foot-candle to 10 foot-candles with the provision of having occupancy-based controls of the light fixtures that would enable 10 foot-candles during time of occupancy and, otherwise, allow lower light levels. This requirement could potentially increase lighting power consumption in stairwells above existing consumption levels if the lights are not turned off for sufficient amounts of time. However, this new requirement potentially opens a great opportunity for the bi-level fixture nationwide as local fire marshals start adopting and implementing the standards.

Since the energy savings would be much higher with the new standards than the existing standards, the product would enjoy a much improved cost-benefit ratio and the payback periods for the product should be improved considerably.

One drawback of the new fire standards is that they require a minimum 15 minute delay for motion sensors in stairwells, which might reduce the energy savings achieved by the bi-level fixtures. The results from the four initial field trials (not available at the time of writing) should determine whether this 15 minute delay should be seen as a major obstruction to energy savings. If so, it may be possible to propose an amendment to the forthcoming California Uniform Fire Code; notice of proposed changes must be received by August 2004.

In the 2005 revision of the California Title 24 energy standards, there are already bi-level lighting control credits for small private offices, classrooms, hallways in hotel/motel, library stacks, and warehouse aisles. Stairwells were also considered for a bi-level lighting control credit, but this was dropped due to lack of appropriate savings and usage data on staircases. If this project succeeds in generating this data, it is possible to propose the addition of stairwells to spaces eligible for bi-level control credits in the next code change cycle.

Strategic Benefits

This project seems to be self-contained, and to offer no strategic benefits.

5.2 HID Electronic Ballast testing

Opportunity for Code Improvement

Preliminary results indicate large variances in performance between ballasts from different manufacturers, and the technology (for dimming HID ballasts) continues to develop on a monthly basis. Manufacturers' data shows that electronic HID ballasts consistently yield better efficacy and longer lamp life than magnetic HID ballasts, so if the third-party results from the LRP study replicate these figures, requirements for electronic ballasts could be included in the California Title 24 and Title 20 standards during the next round of changes.

The major lamp manufacturers are currently introducing miniature HID lamps and ballasts (20-39W) on to the US market, following their successful introduction in Europe. If the US versions of these ballasts prove to be reliable in operation, and save energy without causing other undesirable side-effects such as conducted interference, future revisions of Title 24 could encourage their adoption by increasing the required efficacy of lamps in retail, entertainment and hospitality spaces.

Strategic Benefits

The technologies of HID lamps and especially HID dimming are advancing constantly, and the terminology is often confusing to specifiers and designers. Manufacturers' commercial need for product differentiation and branding seems to take precedence over the clarity of information provided to their customers, and this may have slowed the overall acceptance of new HID technology by the market. The market has been further confused by the introduction during the past five years of ceramic discharge tubes, which are often associated with electronic ballasts.

The market for HID lamps is changing rapidly. Competition from T8, T5 and now CFL lamps in warehouse applications is squeezing the HID market, but metal halide lamps are taking over from high pressure sodium lamps in streetlighting applications. HIDs remain unique because they are the only source that combines high efficacy with a small luminous area, making them very suited to applications such as floodlighting that require a lot of lumens and tight beam control. Strategically, therefore, better understanding of HID technologies among specifiers and designers remains an important goal, and the dissemination of objective third-party information from this LRP project could have a very positive impact on energy use in HID applications.

5.3 Low Glare Outdoor Lighting

Opportunity for Code Improvement

Glare is currently not defined or referred to in Title 24, and the absence of the term reflects the wider uncertainty of knowledge about exactly what glare is and how it can be quantified. It is far from clear whether the performance specification for the Low Glare Outdoor fixture will result in a fixture that gives a low glare sensation to passers-by.

Title 24 uses the IES's definition of a "cutoff" luminaire in its requirement for outdoor lighting of nonresidential buildings (Section 130), but this does not equate with low glare; cutoff requirements serve only to limit light trespass and sky glow.

IES is considering new lighting standards for outdoor lighting that would include requirements for low glare luminaires, and is continuing to develop a methodology to assess outdoor lighting glare and sky glow. Luminaires with low sky glow tend to be more efficient because they use reflectors to concentrate light on the ground, thereby achieving the required illuminance levels with fewer lumens and fewer Watts. The IES recommendations for luminaire types for low glare and low light trespass are also being re-considered in light of findings that full-cutoff luminaires are not entirely effective as low glare luminaires; the definition of glare may turn out to be highly context-dependent. There seems to be no immediate prospect that an agreed criterion for glare (or for visibility) will be included in Title 24.

One of the performance specifications of the low-glare fixture is that it achieves a high uniformity of illumination from a low mounting height. If field trials show that a "wall pack" fixture can achieve levels of efficiency higher than are currently required by Title 24 without causing excessive glare, it might be possible to reduce the allowed lighting power densities of $0.4W/ft^2$ in parking garages (Table 146-A) and 0.04-$0.15W/ft^2$ for general site illumination currently prescribed in Title 24.

Note that the California Title 24 requirements specifically exclude roadway lighting and traffic signage, but include other outdoor signage, facade lighting, and sales canopies amongst other spaces.

Strategic Benefits

The 2005 Title 24 standards introduce a whole new set of regulations for outdoor lighting that aim to reduce the installed wattage of outdoor luminaires through the creation of lighting zones. There are four lighting zones, with Zone 1 corresponding to ecologically sensitive areas such as national and state parks, Zone 2 and 3 with semi-urban and urban areas, while Zone 4 is for areas with need for high illumination. In Zones 1, 2 and 3, the 2005 standards propose to lower installed LPDs and cutoff requirements in order to prevent sky glow and light trespass. However, glare is an important omission. The issue of glare and visibility potentially can have a significant impact on future legislation on outdoor lighting.

5.4 DALI

Opportunity for Code Improvement

The project team is working with NEMA on incorporating the additions to the DALI protocol into the NEMA Standards. After its adoption in the NEMA standards and when commitments from various manufacturers are secured, the DALI specifications could be adopted into other state and national standards such as California Title 20 standards and the Acceptance Testing Requirements.

Strategic Benefits

The DALI protocol project is by its nature strategic, because it facilitates energy savings across a wide variety of applications, and enables better use of existing energy-saving resources.

Appendix A: Total Resource Cost Ratio and Peak Demand Reduction

For convenience, this section combines both TRC and peak demand reduction calculations.

Definition of Terms

Total Resource Cost (TRC) Ratio: Total Resource Cost Ratio is the ratio of the monetary benefits of a measure to its monetary costs. The benefit and cost are defined from a societal perspective, i.e. irrespective of who pays for them, and who receives the benefits.

A TRC Ratio >1 means that the measure should save society money rather than costing it money. There are of course some non-monetary costs and many non-monetary benefits that arise from each measure, but these are not quantified in the TRC calculations.

Formal definitions of the terms used in these calculations can be found in the CPUC's Energy Efficiency Policy Manual[iv].

Unit Goal: Number of units (see "Unit Definition" below) expected to be installed under the incentive program, during the whole (multi-year) life of the program.

Unit Definition: The unit upon which the total resource calculations are based. For instance, this could be either a single luminaire or a room full of luminaires, depending on which is the most useful and convenient definition. The unit definition includes all associated hardware, e.g. control equipment, lamps.

Installation, Service, and Repair Labor Costs: This includes only the costs borne by the utility, not those borne by the customer

Gross Coincident Peak Demand Reduction: The number of kW by which each unit is expected to reduce electrical demand during the peak period, compared to the base case. The Energy Efficiency Policy Manual defines the peak period as noon to 7 p.m. Monday through Friday, June, July, August and September. Whenever possible we have used data for the height of the peak period, 4:00-6:00 pm.:00p.m.),

Gross Annual Energy Savings: The number of kWh by which each unit is expected to reduce annual energy consumption, compared to the base case

Gross Incremental Measure Cost: The difference in installed cost (per unit) between the measure and the base case. This cost must include all additional installation and commissioning costs, and the net present value of any additional maintenance costs.

Expected Useful Life: The average equivalent period for which the measure is expected to continue to produce the savings described above.

Net-to-Gross Ratio: "Net" savings are those that are due only to the program, i.e. all those customers for whom the incentive payment made the difference between buying and not buying the system. "Freeridership" describes savings achieved by customers who would have bought the system even in the absence of the incentive program, but are taking advantage of the incentive payment. Net savings plus freeridership equals gross savings, so the net-to-gross ratio describes the proportion of customers that would not have bought the improved system if they hadn't been given an incentive. For example, 0.8 NTG means that 20% of customers would have bought the improved system even if they hadn't been offered an incentive, whereas 80% have "truly" been incentivized.

Sample TRC Ratios and Peak Demand Reduction Calculations

This section explains in detail how the sample TRC ratios and peak demand reduction values were derived for the LRP products. The purpose of this section is to serve as a template for future reference.

3.3 Classroom Photocell and Control System

Unit Goal

The unit goal for this measure is the same as for the Integrated Classroom Lighting System (see section 4.5 below), except that only those classrooms that are suitable for daylighting (i.e. those with high average daylight factors) would be suitable for this measure. The number of suitable classrooms is not known, but are assumed to be around 50%, making the unit goal for this measure 800 classrooms.

Unit Definition and Baseline

One classroom, 30' x 32' (=960 sq ft) with three rows of recessed fixtures dimmed by row. Lighting power density 0.9W/sq ft. The classroom has manual override of the dimming settings, and no occupancy sensors.

The baseline is a classroom with manual bi-level switching in which occupancy sensors switch the lights off after a 15-minute time delay.

Installation, Service, and Repair Labor Costs

These costs are not expected to be borne by the utility.

Gross Annual Energy Savings

The photocell system would save energy whenever the lights are switched on during daylight hours, regardless of whether the room is occupied or not. Conversely, the energy that would be saved by an occupancy sensor during the day and overnight would be lost.

HMG's bi-level switching study[xv] shows that lights are usually either full-on or off during occupied daylight hours. The flat-topped shape of the daily load profiles in the bi-level study (which suggest that teachers do not switch lights on or off during the day to compensate for daylight) indicate that the likelihood of lights being either on or off remains constant during the day. This means that the estimated percentage lighting energy use (45%) can simply be multiplied by the average duration for which lights are switched on, to derive a figure for energy savings (see Figure 7).

Modifying factor	Effect	Subtotal	Unit	Source
Energy savings from photocell system				
Lights are switched on while the room is unoccupied for 3.6% of the time	(a) = 0.036 * 24 * 7 * 52	314	hours per year	endnote[xv]
Lights are switched on while the room is occupied for 12.9% of the time	(b) = (a) + (0.129 * 24 * 7 * 52)	1441	hours per year	endnote[xv]
New-build classroom measures 30' by 32' and has a lighting power density of 1.2 W/sq ft	(c) = (b) x 30 x 32 x 1.2	1660	kWh per year potential saving	deliverable 3.3.2b, and lighting calcs
Photocell system saves 55% of load	(d) = (c) x 0.55	913	kWh per year	deliverable 3.3.4b
Energy savings lost by not using an occupancy sensor				
Loss of occupancy sensor savings	(e) = (d) - 258	655	kWh per year	energy consumption calcs for 4.5
Lighting-HVAC interaction	(f) = (e) x 1.18	773	kWh per year	endnote[i]
GROSS ANNUAL ENERGY SAVINGS		**773**	**kWh per year**	

Figure 7 - Calculation of annual energy savings for the classroom photocell

Gross Incremental Measure Cost

Modifying factor	Effect	Subtotal	Source
Cost of the classroom photocell	(a) = $150	$150	The Watt Stopper
Cost of replacing the photocell after 8 years	(b) = (a) + $150	$300	The Watt Stopper
Avoided cost of occupancy sensor	(c) = (b) - $75	$225	RS Means, p.268
Incremental cost of dimming ballasts over electronic ballasts	(d) = (c) + 12 x $67 - 12 x $30	$669	RS Means, p.263
Dimming wall switch	(e) = (d) + $50	$719	The Watt Stopper
GROSS INCREMENTAL MEASURE COST		**$719**	

Figure 8 – Calculation of gross incremental measure cost for classroom photocell

Expected Useful Life

16 years; the system relies on both a photocell (standard EUL of 8 years) and fluorescent dimmable fixtures (standard EUL of 16 years). The photocell can be expected to fail

before the fixtures, so the gross IMC includes the cost of replacing the photocell once. The calculations are therefore based on a 16-year expected useful life.

Net-to-Gross Ratio

0.8; this is the standard NTG value for "all other nonresidential programs" from the Energy Efficiency Policy Manual.

Gross Coincident Peak Demand Reduction

Figures from HMG's bi-level switching study[xv] show that classroom lighting loads during peak time average 47%. Load profiles show that almost all of this load is constituted by classrooms in which the lighting is switched fully on.

The Simulation Report (deliverable 3.3.4b) shows that in classrooms that are suitable for daylighting, energy use during the period 8:15am to 3:45pm averages around 45%. This is broadly in line with a variety of research findings in the Complementary Research Review (deliverable 6.3.4). This figure of 45% assumes average sky conditions and 12-month operation, so energy use during peak times can be assumed to be much lower than this; without stretching credulity, energy use could be assumed to be 35% during peak times.

Modifying factor	Effect	Subtotal	Unit	Source
Initial value: average peak lighting load in classrooms	(a)	47%	% load reduction	endnote[xv]
Photocell system reduces peak load by 65% in those classrooms in which the lights are switched on.	(b) = (a)* 0.65	31%	% load reduction	modified from deliverable 3.3.4b
Standard classroom measures 30' by 32' and has a lighting power density of 1.2 W/sq ft	(c) = (b) x 30 x 32 x 1.2	357	W per classroom	deliverable 3.3.2b, and Title 24 2005
Loss of peak load reduction due to occupancy sensors	(d) = (c) - 18	339	W per classroom	peak demand reduction calcs for 4.5
Lighting-HVAC interaction	(e) = (d) x 1.18	400	W per classroom	endnote[i]
COINCIDENT PEAK DEMAND REDUCTION		**400**	**W per classroom**	

Figure 9 - Coincident Peak Demand Reduction Calculation for Classroom Photocell

4.1 Hotel and Institutional Bathroom Lighting Project

It should be noted that two different versions of the nightlight sensor have been developed: the first version has an LED nightlight and an occupancy sensor built in to a wall switch; the second version has an LED nightlight and an occupancy sensor factory-fitted into a "vanity unit" light fixture. The first version is designed to be retrofitted into guestrooms whereas the second is designed to be installed in guestrooms that are being newly constructed or remodeled. The analysis is conducted for the wall switch nightlight only. The project team is also developing a fixture integrated nightlight that is expected to have greater savings due to reduction in installed wattage, and is expected to have a higher TRC ratio.

Unit Goals – New Construction and Remodeling

The Energy Information Administration's Commercial Buildings Energy Consumption Survey (CBECS)[v] table B9 shows that approximately 80 million square feet of lodging was built in the US per year, during the period 1990-2000. We have used this figure as a starting point to calculate the unit goal, as shown in Figure 10.

Modifying factor	**Effect**	**Subtotal (new rooms)**	**Subtotal (retrofits)**	**Unit**	**Source**
Initial value	(a)	80,000,000	sq ft per year	CBECS database, table B9[v]	
Assumption that the rate of construction of lodging over the next few years will be the same as for 1990-2000.	None	80,000,000		sq ft per year	n/a
Assumption that California's share of this new construction is proportional to its population	(b) = (a) x 34/294	9,252,000		sq ft per year	n/a
Assumption that 75% of this floorspace is guest rooms	(c) = (b) x 0.75	6,939,000		sq ft per year	n/a
Assumption that the average room measures 15'x30'	(d) = (c) ÷ 450	15,420		rooms per year	n/a
Assumption that the number of hotel rooms retrofitted with light fixtures is double the number of new hotel rooms	(e) = (d) x 3	15,420	30,839	rooms per year	n/a
Assumption that program goal is 5% market share	(f) = (e) x 0.05	771	1542	rooms per year	n/a
Incentive program will last for two years	(g) = (f) x 2	1542	3084	rooms	n/a
UNIT GOAL, assuming that half the rooms are in "vacation" hotels, and half are in "business" hotels		771	1542	rooms in "vacation" hotels	
		771	1542	rooms in "business" hotels	

Figure 10 – Calculation of unit goal for bathroom lighting project

Data from the 2002 NRNC Market Characterization for Southern California Edison shows 4,342,000 sq ft of hotels built in CA. Using the method described above, this would lead to a unit Goal of 3600 rooms (rather than 4600 as estimated above). Since the data used in Figure 10 above is based on a 10-year average, while the SCE data is based on one year -- which could have been a slow year for hotel construction in California due to the energy crisis, lower economic growth and several other factors -- the unit goal numbers for the project are based upon CBECS.

Retrofits

Data from the 1997 US Economic Census cited on the Technology Transfer Plan (deliverable 4.1.5a) shows that there are 365,800 hotel guestrooms in California. All of these are potentially suitable for the wall switch version of the LED nightlight.

Incidentally, comparing the above estimate of 365,800 guestrooms with our estimate that 46,260 guestrooms are either built from scratch or refurbished each year, puts the average life of a hotel room at 7.9 years. This seems intuitively reasonable and seems to support the unit goal for the light fixture version of the LED nightlight.

Unit Definition

The first version of the LED nightlight comprises a standard wall switch fitted with an LED nightlight and an infra-red occupancy sensor. The second version comprises a standard commercially available fluorescent light fixture, factory-fitted with an LED nightlight and an infra-red occupancy sensor. In this section we concentrate on the wall switch version only.

Installation, Service, and Repair Labor Costs

These costs are not expected to be borne by the utility.

Gross Annual Energy Savings

The project team monitored the use of a number of prototype units at a Doubletree hotel (see deliverable 4.1.2). The average bathroom vanity light at the Doubletree hotel had a load of 180W; we have used this figure as a starting point to calculate annual energy savings, as shown in Figure 11. We have not taken into account energy savings that would accrue from replacing the existing fixtures with lower-wattage fluorescent fixtures, so these results are valid only for the retrofit wall switch unit:

Modifying factor	Effect	Subtotal (business hotel)	Subtotal (vacation hotel)	Unit	Source
Initial value	(a)	0.180	0.180	kW per fixture	deliverable 4.1.2
Fixtures were switched on for an average of 4.42 hours per day without the nightlight, and 2.37 hours per day after the nightlight was installed	(b) = (a) x (4.42 – 2.37)	0.369	0.720	kWh per day	deliverable 4.1.2b
Nightlight consumes 4W and is switched on for 21.63 hours per day (on days room occupied)	(c) = (b) - 21.63 x 0.004	0.282	0.633	kWh per day	deliverable 4.1.2b
The average hotel room is occupied 61% of the days in the year	(d) = (c) x 0.61 x 365	63	141	kWh per year	Selwitz, R, *PWC: business should improve during 2004*, Hotel & Motel Management, Jan 12, 2004
Nightlight consumes 4W during unoccupied days (39% of the year)	(e) = (d) - 0.39 x 24 x 365 x 0.004	50	127	kWh per year	deliverable 4.1.2b
GROSS ANNUAL ENERGY SAVINGS		**50**	**127**	**kWh per year**	
***http://articles.findarticles.com/p/articles/mi_m3072/is_1_219/ai_112654945)**					

Figure 11 – Calculation of gross annual energy savings for bathroom lighting project

Gross Incremental Measure Cost

For the first, wall switch version, the estimated cost of the unit (from the Technology Transfer Plan (deliverable 4.1.5a) is $35. The estimated cost of retrofitting this into a wall switch is $30 (30 minutes work at $60 per hour). The gross IMC for the first version is therefore $65.

For the fixture-mounted version, the nightlight and occupancy sensor are factory-fitted as part of a new luminaire. The Technology Transfer plan (deliverable 4.1.5a) quotes the cost of the motion sensor and LED nightlight at $35, and the estimated cost of modifying the fixture and fitting the unit at $30 (30 minutes work at $60 per hour). The gross IMC is therefore the same as for the first version - $65.

Expected Useful Life

8 years; this is the standard EUL for lighting occupancy sensors, from the Energy Efficiency Policy Manual.

Net-to-Gross Ratio

0.8; this is the standard NTG value for “all other nonresidential programs” from the Energy Efficiency Policy Manual.

Gross Coincident Peak Demand Reduction

The Performance Analysis (deliverable 4.1.2b) gives a graph of electrical demand before and after installation of the unit. Averaging values from the peak period (12:00-6:00 p.m.) shows that the unit saves 7.1% of the installed load (roughly 40% of the actual load before installation).

Applying this 7.1% to the average installed load of 180W gives a peak demand reduction of 12.8W per unit.

4.3 Energy-Efficient Retrofit/Remodel Alternative to Incandescent Downlights

In analyzing this project, we have compared the fixture with a 65W R-30 incandescent, rather than with another high-efficacy fixture such as a 26W CFL downlight. The rationale for this is that the reduced cost of the LRP fixture makes it competitive with R-30 fixtures, and so builders might use the LRP fixture in place of an incandescent, for instance in kitchens where 50% of the lighting watts can still be made up of low-efficacy fixtures under the requirements of Title 24 2005. Compared with a standard 26W CFL fixture the LRP fixture offers little to no energy savings, but does offer a reduction in cost.

Unit Goal

Data from the California Department of Finance[vi] shows that, if present trends continue, around 250,000 new homes will be built per year in California over the next few years. This figure includes both multi-family (around 70,000) and single-family (around 180,000) homes.

The Market Assessment Report (deliverable 4.3.1a) shows that new single-family homes have approximately 6 kitchen downlights. This puts the potential market for the product at 1.5 million downlights per year. Given this huge potential market, a unit Goal for an incentive program seems arbitrary, so we have used a figure of 20,000 over a two-year incentive program.

Unit Definition

Despite the fact that the fixture has a single ballast supplying two lamps in two separate reflectors, in order to avoid confusion when figures from this project are compared with figures from other projects, we will define the unit as being one single downlight head.

Each head comprises a low-glare specular reflector in an IC-AT housing and a 26W compact fluorescent lamp. A gasket is used to achieve airtightness between the housing and the ceiling sheetrock, as required by Title 24 2005.

Installation, Service, and Repair Labor Costs

These costs are not expected to be borne by the utility.

Gross Annual Energy Savings

A study by Jennings et al.[vii] for Tacoma Public Utilities, later cited by Mills et al.[viii] showed that the average residential light fixture was switched on for 1.8 hours per day, although kitchen fixtures were cited as an example of high-use fixtures that are likely to be switched on for longer periods.

HMG's Residential Lighting Baseline[x] found that kitchen fixtures were switched on for an average of 3.4 hours per day. HMG showed that, across all room types fluorescents were likely to be switched on for longer than other lamp types, but the reason for this was not determined (for instance, it could be that users want to extend lamp life, because the fixtures' low energy consumption leads them not to care about energy use so much, or because CFLs are more likely to be installed in high use fixtures). The usage figures were 3.1 hours per day for CFL, 2.2 for incandescent.

For these calculations we have used the HMG figure of 3.4 hours per day, which when multiplied by the 40W difference between the high efficiency fixture and a 65W R-30 incandescent, gives an annual energy saving of 50 kWh/year. Adding an additional 18% for lighting-HVAC interaction gives a figure of 59 kWh/year.

Gross Incremental Measure Cost

The Technology Transfer plan (deliverable 4.3.2a) gives an expected "distribution house cost" for the luminaire of $73.65 ($36.83 per unit, since each head is one unit). Assuming a 40% retail markup, the cost of the fixture is projected at $51.50. From RS Means[ix], the cost (excluding installation) of a regular downlight fixture is $36.60, the difference in cost is therefore around $15.

There is likely to be a slight reduction in installation time due to the use of one ballast rather than two (estimated at $5) means that the incremental measure cost is estimated at $10 per head.

Expected Useful Life

16 years; this is the standard EUL for a compact fluorescent fixture, from the Energy Efficiency Policy Manual.

Net-to-Gross Ratio

0.8; this is the standard NTG value for "all other residential programs" from the Energy Efficiency Policy Manual.

Gross Coincident Peak Demand Reduction

A 1996 report from HMG[x] showed that kitchen and dining room lights, like most residential fixtures, have a 5% likelihood of being switched on during most of the morning and afternoon, but that this percentage increases rapidly after 16:00. Since the statewide afternoon load peak reaches its maximum between 16:00 and 18:00, we have used the average value over this period (20%).

For the purpose of this calculation we have assumed that the energy-efficient downlight will act as a direct replacement for a 65W R-30 incandescent spotlight. This is corroborated by a finding in the HMG baseline study that, within the 40-100W incandescent range (the lamps typically used in kitchen downlights), the average lamp wattage used was 57W.

The power consumption of the ballast used in the energy-efficient fixture is around 50W[3], 25W per head, so the saving would be 0.2 x (65-25) = 8W. This should be increased by a further 18% to allow for lighting-HVAC interaction. This gives an estimated peak demand reduction of 9.4W.

4.5 Integrated Classroom Lighting System

Unit Goal

There are several different sources of information that allow complementary estimates of the unit goal for the ICLS to be made. These estimates (A-C) are shown below in Figure 12, Figure 13, and Figure 14. They lead to very similar estimates, of around 1600 classrooms as the unit goal for project 4.5.

Firstly, statistics from the California Office of Public School Construction[xi] show that there are 1,031,000 pupils in the state for whom new schools are required during the next five years. There are also 1,104,000 pupils for whom classroom modernizations are required. These estimates are based on the state's classroom loading standard (25 pupils per classroom for K-6 and 27 per classroom for 7-12). This allows an estimate of new construction and modernization to be, as shown in Figure 12.

[3] Source: discussion with project team. The ballast is under-running the lamps.

Modifying factor	Effect	Subtotal		Unit
		K-6	7-12	
New construction over the next five years				
Number of eligible pupils	(a)	429725	601216	pupils
Target number of pupils per classroom	(b)	25	27	pupils per classroom
Number of classrooms required	(c=a/b)	17189	22267	classrooms
Modernizations over the next five years:				
Number of eligible pupils	(d)	499289	604312	pupils
Target number of pupils per classroom	(e)	25	27	pupils per classroom
Number of classrooms required	(f=d/e)	19972	22382	classrooms
Total number of new classrooms	(g=c+f)	37161	44649	classrooms
Combined total of K-6 and 7-12 classrooms	(h)	81810		new classrooms required in the next five years
Assumption that the incentive program will last for two years	(i) = (h) x 2/5	32724		new classrooms required during the program
Assumption that program goal is 5% market share	(j) = (i) x 0.05	1636		units
UNIT GOAL		**1636**		**units**

Figure 12 – Calculation A of the unit goal for the classroom lighting system

The unit goal from calculation A is corroborated by Southern California Edison's Nonresidential New Construction Database[xii], which gives a figure of 15,143,000 sq ft of new school construction in California for 2002. This leads to a second estimate (calculation B) for the unit goal, as shown in Figure 13.

Modifying factor	Effect	Subtotal	Unit	Source
Initial value	(a)	15,143,000	sq ft of new school buildings per year	endnote[xii]
Assumption that classrooms make up 50% of new school building floorspace	(b) = (a) x 0.5	7,572,000	sq ft of new classrooms per year	n/a
California classrooms typically measure 32'x30'	(c) = (b) ÷ 960	7,887	new classrooms per year	deliverable 3.3.2b
Assumption that the number of classrooms remodeled per year is the same as the number of new classrooms	(d) = (c) x 2	15,774	units per year	n/a
Assumption that program goal is 5% market share	(e) = (d) x 0.05	787	units per year	n/a
Assumption that the incentive program will last for two years	(f) = (e) x 2	1577	units per year	n/a
UNIT GOAL		**1577**	**units**	

Figure 13 – Calculation B of the unit goal for the classroom lighting system

The unit goal from calculation B is further corroborated by Commercial Buildings Energy Consumption Survey (CBECS) data[xiii] that shows that during the period 1990-1999, 1,239M square feet of new educational floorspace was constructed nationally. This figure leads to a third estimate (calculation C) for the unit goal, as shown in Figure 14.

Modifying factor	Effect	Subtotal	Unit	Source
Initial value	(a)	1,239	M sq ft of new educational buildings nationally, 1990-1999	endnote[xiii]
Assumption that California's share of educational construction is proportional on a per-capita basis	(b) = (a) x 34 ÷ 290	145	M sq ft of educational buildings	n/a
Assumption that educational building construction is continuing at the same rate, and assuming a two-year incentive program	(c) = (b) ÷ 10 x 2	29	M sq ft of educational buildings	n/a
Assumption that classrooms make up 50% of new school building floorspace	(d) = (c) x 0.5	15	M sq ft of new classrooms	n/a
California classrooms typically measure 32'x30'	(e) = (d) ÷ 960	15131	new classrooms	deliverable 3.3.2b
Assumption that the number of classrooms remodeled per year is the same as the number of new classrooms	(f) = (e) x 2	30263	units	n/a
Assumption that program goal is 5% market share	(g) = (f) x 0.05	1513	units	n/a
UNIT GOAL		**1513**	**units**	

Figure 14 – Calculation C of the unit goal for the classroom lighting system

Unit Definition

One classroom, 30' x 32' (=960 sq ft) with two rows of suspended fixtures, one occupant sensor, teacher control center including an "A/V mode" switch, fixtures switched by row. Lighting power density 0.9W/sq ft.

Installation, Service, and Repair Labor Costs

These costs are not expected to be borne by the utility.

Gross Coincident Peak Demand Reduction

Any reduction in peak demand needs to be judged relative to an established baseline level of energy consumption when only manual switching is installed in the classroom. During occupied periods, if the Integrated Classroom Lighting System uses manual on-switching, the energy consumption can be assumed to be the same as for the manual switching baseline. During unoccupied periods, the ICLS is designed to achieve lighting energy savings by switching off lights that might have been left switched on by occupants (although whether energy savings are typically achieved in practice is far from clear[xiv])..

The calculations shown in Figure 15 are based on a study on bi-level manual switching patterns in classrooms[xv]. The study provides data for unoccupied periods, but does not differentiate peak from non-peak times, so the data includes all times of day including night time. During unoccupied periods on weekdays, classrooms average 9% lighting energy consumption. This 9% consumption is the basis for calculation of the peak demand reduction achieved by the ICLS, as described in Figure 15:

Modifying factor	**Effect**	**Subtotal**	**Unit**	**Source**
Initial value	(a)	9%	peak lighting load reduction	endnote[xv]
Standard classroom measures 30' by 32' and the ICLS has a lighting power density of 0.9 W/sq ft	(b) = (a) x 30 x 32 x 0.9	78	W per unoccupied classroom	deliverable 3.3.2b, communications with project team
Assumption that classrooms are unoccupied for 75% of the time during peak periods	(c) = (b) x 0.25	20	W per classroom	n/a. Note that peak period extends beyond typical school hours
Assumption that the occupant sensor time delay is set to 15 minutes, and that unoccupied daytime periods last for an average of one hour	(d) = (c) x 0.75	15	W per classroom	n/a
Lighting-HVAC interaction	(e) = (d) x 1.18	18		endnote[i]
COINCIDENT PEAK DEMAND REDUCTION		**18**	**W per classroom**	

Figure 15 – Calculation of coincident peak demand reduction for classroom lighting system

Gross Annual Energy Savings

We have used two sources of information to estimate gross annual energy savings for the Integrated Classroom Lighting System; the first is the case study of Heritage Oaks School conducted by the ICLS project team as part of the LRP, and the second is HMG's study on bi-level switching in classrooms[xv].

In the case study, the school had a particular type of recessed lighting system before the ICLS was retrofitted – this lighting system provides the baseline for the estimates derived from the case study (scenarios A-D). To make these estimates more representative of typical classrooms we have adjusted the savings from the case study in line with typical classroom conditions as found in the bi-level study, and as dictated by Title 24.

For the estimate based on the bi-level study (scenario E), the baseline was taken to be the technology that offers the cheapest route to compliance with Title 24 2005. In practice, we expect that the cheapest route will be the use of recessed lensed fixtures controlled by a time clock with a manual override switch.

Scenarios A-D

Data from the Heritage Oaks School case study are reproduced below in Figure 16. The energy saving figures from the case study were much higher than we had expected, and this is explained in part by the very high lighting energy consumption of Heritage Oaks School before the retrofit. The annual consumption of 5983 kWh per classroom means that the lights were switched on for 37.9% of the time during the year (including nights, weekends, holidays, etc). In the bi-level switching study, the lights in the average classroom were switched on for only 17.8% of the time. The energy savings reported in the Heritage Oaks case study have been scaled down by the ratio of these percentages, to bring them in line with more typical usage. This scaling down is appropriate as long as the difference in hours of lighting use is due to longer hours of occupancy of the building (i.e., if Heritage Oaks School is used after-hours), but would not be appropriate if the long hours of lighting use at Heritage Oaks are due to staff leaving the lights on overnight.

Even after this scaling down, the energy savings from the case study are still more than double those predicted by the bi-level study (scenario E). This may be due to a number of factors such as the particular daylighting strategies of the case study classrooms, the training of the teachers, or the hours of use.

Scenario E

The bi-level study cited above showed that classrooms were unoccupied with the lights on for 4.1% of the time (over a 24 hour, 7 day per week baseline). This 4.1% breaks down as 3.6% of the time at full output, 0.2% at high-only, and 0.3% at low-only.

These percentages can be used to calculate a good approximation to the amount of energy saved, because the high-only circuits averaged 0.797 W/sq ft while the low-only circuits averaged 0.703 W/sq ft. Full output required both the low and high circuits to be switched on. Hence the total estimated energy saving can be calculated, as shown in Figure 17.

The values for TRC given at the beginning of this report represent the widest range of values given in Figure 17 and Figure 16.

Modifying factor	Effect	Subtotal				Unit
Initial value(pre-retrofit lighting energy consumption)	(a)	5983				kWh per year per classroom
		Scenario A: 2 rows, switching	Scenario B: 2 rows, dimming*	Scenario C: 3 rows, switching	Scenario D: 3 rows, dimming*	
Control, modified from 1.8W/sq ft to 1.2W/sq ft typical new construction	(b = a * 1.2 / 1.8)	3989	3989	3989	3989	kWh per year per classroom
Recorded energy consumption of ICLS	(c)	2778	2569	2464	2458	kWh per year per classroom
Difference due to ICLS	(d = b – c)	1211	1420	1525	1531	kWh per year per classroom
Scaling factor to bring hours of use in line with typical figures from the bi-level study	(e = d * 17.9 / 37.9)	572	670	720	723	kWh per year per classroom
GROSS ANNUAL ENERGY SAVING		**572**	**670**	**720**	**723**	**kWh per year per classroom**
*In the case study, some of the classrooms had an additional level of functionality that allowed the teacher to dim the downlight portion of the light fixture using a wall-mounted dimming control. This was known as the "AV mode"						

Figure 16 – Scenarios A-D: Calculation of annual energy savings for classroom lighting system (based on Heritage Oaks School case study, project deliverable)

Modifying factor	Effect	Subtotal	Unit	Source
3.6% of the time spent at full output during non-occupied periods	(a) = 0.036 x (0.797 + 0.703)	0.0540	W/ sq ft	endnote[xv]
0.2% of the time spend at high-only during non-occupied periods	(b) = (a) + 0.002 x 0.797	0.0556	W/ sq ft	endnote[xv]
0.3% of the time spend at low-only during non-occupied periods	(c) = (b) + 0.003 x 0.703	0.0577	W/ sq ft	endnote[xv]
Classroom measures 30’ by 32’	(d) = (c) x 30 x 32	55.4	W per classroom	deliverable 3.3.2b
Savings sustained for an entire year	(e) = (d) x 24 x 365 / 1000	485	kWh per year per classroom	n/a
Scaling these savings down for a new-build 0.9W/sq ft classroom, rather than the average 1.5W/sq ft classrooms in the bi-level study	(f) = (e) x 0.9 / 1.5	291	kWh per year per classroom	lighting calcs
Assumption that the occupant sensor time delay is set to 15 minutes, and that unoccupied daytime periods last for an average of one hour	(g) = (f) x 0.75	218	kWh per year per classroom	n/a
Lighting-HVAC interaction	(h) = (g) x 1.18	258	kWh per year per classroom	endnote[i]
GROSS ANNUAL ENERGY SAVINGS		**258**	**kWh per year per classroom**	

Figure 17 – Scenario E: Calculation of annual energy savings for classroom lighting system (switching only)

Gross Incremental Measure Cost

As noted in “Unit Goal” above, we have assumed that the base case for comparison is the cheapest system that allows compliance with Title 24 2005. This would be a system of recessed lensed fixtures controlled by a time clock system with manual override as described in Title 24 section 131. To achieve the Title 24 requirement of 1.2 W/sq ft, 12 fixtures would typically be used. The base case does not include occupancy sensors, since then there would be (on paper) no difference in energy consumption between the base case and the ICLS. Gross IMC has been calculated as shown in Figure 18: Note that the IMC for Scenario E is the same as for Scenario A.

Modifying factor	Effect	Subtotal				Source
		Scenario A/E: 2 rows, switching	Scenario B: 2 rows, dimming*	Scenario C: 3 rows, switching	Scenario D: 3 rows, dimming*	
Installed cost of the ICLS	(a)	$2600	$3100	$3700	$4200	Finelite
Installed cost of one replacement occupancy sensor (see "Expected Useful Life" below)	(b) = (a) + $125	$2725	$3225	$3825	$4325	RS Means, p.268, modified to require 0.5 hours' labor
12 recessed lensed fixtures (2' x 4', 3 lamp, consumes around 1.2Wsq ft, typical new classroom)	(c) = (b) - 12 x $158	$829	$1204	$1929	$2429	RS Means, p.260
Clock dial time switch with enclosure	(d) = (c) - $90	$739	$1114	$1839	$2339	RS Means, p.183
Interval timer wall switch to override clock	(e) = (d) - $58	$781	$1056	$1781	$2281	RS Means, p.180
Regular bi-pole wall switch	(f) = (e)- $62	$619	$994	$1719	$2219	RS Means, p.181
GROSS INCREMENTAL MEASURE COST		**$619**	**$994**	**$1719**	**$2219**	

Figure 18 – Calculation of gross incremental measure cost for classroom lighting system

Expected Useful Life

16 years; the system relies on both an occupancy sensor (standard EUL of 8 years) and fluorescent fixtures (standard EUL of 8 years). The occupancy sensor can be expected to fail before the fixtures, so the gross IMC includes the cost of replacing the occupancy sensor once. The calculations are therefore based on a 16-year expected useful life.

Net-to-Gross Ratio

0.8; this is the standard NTG value for "all other nonresidential programs" from the Energy Efficiency Policy Manual.

5.1 Bi-Level Stairwell Fixture Performance

Francis Rubinstein, Lawrence Berkeley National Laboratory

Unit Goal

Data on the number of stairwell, number of landings and their square footage is not readily available, but the Technology Transfer Plan (deliverable 5.1.3) contains an extensive analysis of available data that leads to an estimate of 30,000 fixtures per year in California. We have assumed 5% market penetration during the incentive program, and that the incentive program would last for two years; these assumptions lead to a goal of 3000 fixtures during the life of the program.

Since the initial data from LBNL's monitoring of high-rise buildings on the Berkeley Campus shows that the greatest savings are achieved on landings above the second story, we recommend that an incentive program should concentrate on high-rise rather than low-rise buildings.

Unit Definition

One landing lit by a single 2x32W T8 bi-level fixture with integral ultrasonic occupancy sensor. Fixture consumes 62W at full output, 7W at minimum output (3% light output).

Installation, Service, and Repair Labor Costs

These costs are not expected to be borne by the utility.

Gross Annual Energy Savings

As part of this project, LBNL monitored the staircases of four multi-storey buildings on the Berkeley campus. They found that, on average, the stairwell light fixtures would be at full output for 269 minutes per day, and at low output for 1171 minutes per day. The time spent at low output represents a saving over the base case in which the fixture would be constantly at full output. The expected annual energy saving is shown in Figure 19.

Modifying factor	Effect	Subtotal	Unit	Source
Initial value	(a)	1171	minutes per day in low output state	initial results from LBNL, personal communication with Francis Rubinstein
60 minutes per hour, 365 days per year	(b) = (a) / 60 x 365	7124	hours per year in low output state	n/a
Difference in electrical load between high output and low output states	(c) = (b) x (62-7)	392	kWh per year	n/a.
GROSS ANNUAL ENERGY SAVINGS		**392**	**kWh per year**	

Figure 19 - Calculation of annual energy savings for bi-level stairwell fixture

This represents an energy saving of around 72%, which is very similar to the 60% savings reported by the Lighting Research Center in a study of a multi-storey commercial building in Manhattan.

Gross Incremental Measure Cost

Gross IMC has been calculated as shown in Figure 20. It should be noted that dimming fluorescent lamps to low levels can reduce the life of the lamp. This effect varies considerably from one lamp to another because fluorescent lamps employ different types of circuit to regulate current at low levels. The effect on lamp life in this case is not known.

Modifying factor	Effect	Subtotal	Source
Retail cost of the stairwell fixture	(a)	$187	Technology Transfer Plan
Installed cost of one replacement occupancy sensor (see “Expected Useful Life” below)	(b) = (a) + $125	$312	RS Means, p.268, modified to require 0.5 hours’ labor
Retail price of a conventional staircase lighting fixture (surface mounted 4’ x 2’, 2x32W T8)	(c) = (b) - $78	$234	RS Means, p.260
Difference in fixture installation time	(d) = (c) - $0	$234	
Assume that the time required to commission each occupancy sensor is 30 minutes at $60/hr, = $30	(e) = (d) + $30	$264	
GROSS INCREMENTAL MEASURE COST		**$264**	

Figure 20 – Calculation of gross incremental measure cost for bi-level stairwell fixture

The ultrasonic presence detectors will have to be carefully commissioned to ensure that each sensor is triggered by movement on adjacent landings. It is not known how long this will take, and how often re-commissioning may be required. The estimate of 30 minutes per landing is not based on research data or RS Means time estimates.

Expected Useful Life

16 years; the system relies on both an occupancy sensor (standard EUL of 8 years) and fluorescent fixtures (standard EUL of 16 years). The occupancy sensor can be expected to fail before the fixtures, so the gross IMC includes the cost of replacing the occupancy sensor once. The calculations are therefore based on a 16-year expected useful life.

Net-to-Gross Ratio

0.8; this is the standard NTG value for “all other nonresidential programs” from the Energy Efficiency Policy Manual.

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PIER Lighting Research Program

California Energy Commission
Contract # 500-01-041

Lighting Standards Needs Assessments

Deliverables 6.3.3-6.3.6

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Lighting Standards Needs Assessments
Project 6.3 Lighting R&D/Codes Scoping Study

1. INTRODUCTION

The purpose of this report is to describe those areas of research where the PIER (Public Interest Energy Research) program could support updates to the California energy codes and assist the state in its goals of reducing per capital energy consumption and electrical demand.

1.1 PIER GOALS TO IMPACT MARKETS

The Public Interest Energy Research (PIER) program has a stated goal of decreasing "building energy use through research that will develop or improve energy efficient technologies, strategies, tools, and building performance evaluation methods." Though the primary thrust of this goal is to support research that improves the energy efficiency of buildings, implicit in this statement is that the research will actually make it into the market where it will decrease building energy use. One strategy to insure widespread market penetration is to have code adoption as an ultimate goal for a PIER project. If a product or finding resulting from PIER were adopted into the state energy codes, then the market effect will be fairly certain, since the codes would then require that type of technology, process, or another measure of equal efficiency to be implemented in all new buildings. Thus, identifying code adoption as an ultimate goal for a PIER program insures that it will have a large and permanent market impact. This report presents code adoption driven research activities that have been identified through consultations with the California Energy Commission Staff, California Investor Owned Utility staff, and code consultants in the state of California.

1.2 ENERGY CODES BASED ON ESTABLISHED TECHNOLOGIES

It is important to recognize that the code adoption goal involves a different strategy than research and development of new innovative energy efficiency technologies. This is because code adoption happens at the end of a very long market development process, whereas innovative technologies may enter the market at the beginning. Figure 1 illustrates this concept, where the market for energy efficiency can be segmented in terms of a willingness to embrace new technology from "Innovators" to "Laggards."

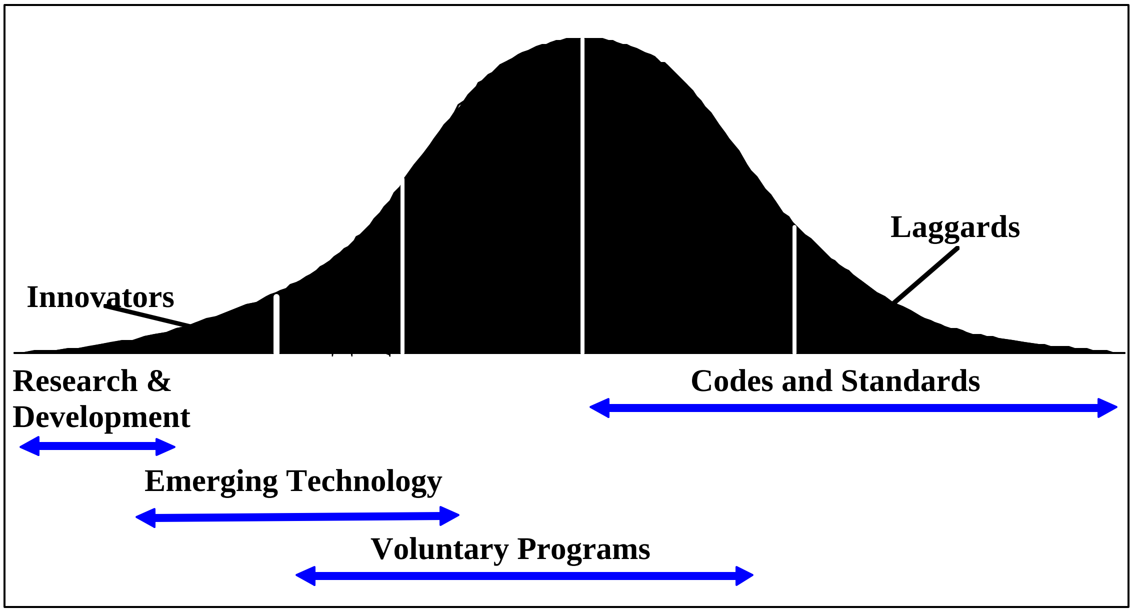


Figure 1: Market segments and diffusion of energy efficiency innovations[1]

It is the innovators, at the front end of the market, who have been the focus of PIER research directed at developing new energy efficient products. At the end of an R&D program, there may be the nucleus or idea for a new product, but also an expectation that investors and/or industry will take on the responsibility of the next steps to commercialize the product. However, this is often a very difficult and uncertain task. Many new products are introduced, but few survive the initial demands of the marketplace. Getting a new research idea to market—past regulatory compliance, manufacturing constraints, and consumer acceptance —is sometimes called the "valley of death" because there is so little public funding to help this process and it is hard to sustain a company on the small market share afforded to new products.

When a product is commercially available, there tends to be an ever growing level of support for each step of introduction into the market. The first small step might be assisted by one of the emerging technology (ET) programs run by the California investor owned utilities. These ET programs identify and support technologies or practices that are promising, but have yet to make a significant dent into the market. Oftentimes, these programs target early adopters who will provide a case study site where the technology can be tested under field conditions. These case studies help identify final production and application problems, provide objective data for marketing materials, and a small initial market for the product while production ramps up.

Once the initial problems have been solved and feasibility of a new energy efficiency product has been demonstrated, the market is larger and public funds to support expansion of the market are likely to grow much larger. At this point, large incentive-based programs are often targeted towards the market as a whole to purchase energy efficiency resources, increasing demand for the product and helping to increase

[1] Illustration based upon 'Diffusion of Innovations' by Everett M. Rogers.

production. If the product is seen as cost effective by the market, it may become standard practice without further support. If there are split incentives or other structural market barriers, it may require continued program support or a targeted market transformation program to help it become standard practice.

Once the technology has moved through all these stages, and has been shown to save energy reliably and cost-effectively and does not cause any significant disruptions to the other uses of buildings (visibility, acoustics, indoor air quality, aesthetics etc.), then it may become a candidate for inclusion into the energy codes. In general, the purpose of the energy codes is simply to eliminate the worst building design practices of the "Laggards" in favor of the standard practices of the majority, rather than to encourage the best practices of the "Innovators".

For a measure to be incorporated into the building efficiency standards, it must pass a number of tests. It should be noted that mandatory measures have the most stringent eligibility tests, while compliance options and allowances have a less stringent threshold for inclusion in codes. In general, not only must the energy savings be well characterized and substantial, but each measure must be shown to be:

- cost-effective based on current installed costs
- commercially available from more than one manufacturer
- feasible and compatible with current building practice
- have no net negative environmental or health impacts

Thus, many of the code-readiness questions related to market acceptance, pricing, and feasibility render the newest, most innovative technologies unlikely candidates for inclusion into the building energy efficiency standards. In general, technologies that are considered for inclusion into energy codes already have a significant market position and a track record of reliable energy savings and known interactions with other building components.

As described in the companion report, "PIER Lighting Research Program: Prioritized R&D / Standards Connections," (Deliverable 6.3.5), "Because the technologies in the LRP portfolio have, by their nature, not yet been successful in the open market, they cannot yet be considered ready to influence standards." This report then goes on to rank the projects by their relative development and their near term total resource cost ranking for inclusion into voluntary energy efficiency programs. Since the projects were not developed or selected to answer energy code questions, but rather to develop innovative technologies, it is not surprising that there was minimal code connection.

1.3 ENERGY CODES NEED BASIC RESEARCH

Energy codes are predicated on the assumption that all of the requirements in the standards are "good practice" and they are cost-effective, do not violate the safety or structural requirements, and are compatible with typical uses of buildings. In addition, when new technologies or design practices are adopted into the standards, it is expected that the life cycle energy cost savings of the new requirement *as compared to minimally* *compliant buildings as they are currently operated* without the requirement is less than the incremental cost of the measure.

However, since we have little information on how people use their lighting, it is difficult to estimate the energy savings of efficient lighting technologies. We do not know how long lights are operating for every occupancy type, we do not know with any great precision what lighting technologies are being installed in new buildings, and we do not know how well designers are complying with the existing standards. Thus, it is hard to estimate what the base case is for installed lighting wattage and even harder to estimate base case energy consumption. If we have a hard time estimating base case energy consumption, it makes it almost impossible to estimate savings.

As described earlier, estimating energy consumption is but a small subset of the questions that have to be answered when considering a new code measure. The purpose of the energy codes is to save energy not create problems. Thus, the standards have to consider whether there are consumer or user acceptance problems, and reliability or other concerns with requirements for a given technology. Since long term savings is desired, there has to be some evaluation of the persistence of the savings.

Some of these questions cannot be answered in the short time period immediately preceding the code adoption hearings. Some of these research questions require medium term data collection periods. This type of basic research fits well with the PIER program's skill set of independent and technically competent third-party research. Outside of the codes and standards sections of the utility efficiency programs, the only other source of funding for this research is by manufacturers of affected technologies – not a recipe for objective analysis.

In general, the thrust of utility programs including codes and standards is for short term acquisition of "resources" to reduce peak demand. The longer term projects to support the fundamental basis of the standards (how well are standards enforced, how do people really design buildings, how do people really operate buildings etc,) need an "owner" like PIER. PIER can complement the technical support that is currently being provided by the codes and standards divisions of the investor-owned utilities as part of their public goods programs. Indeed, PIER projects helped develop the knowledge base that was the basis of several changes to the 2005 building efficiency standards including skylighting, duct sealing, acceptance testing, and insulation position measures.

1.4 ORGANIZATION OF REPORT

This report is organized into the following sections:

- **2005 Code Changes Review and Remaining Issues** – this section describes the major code revision in the building efficiency standards that take effect in 2005. It also describes which measures were dropped due to industry opposition or lack of reliable information. This helps identify holes in current knowledge that have to be addressed if some measures are going to be considered for inclusion in the standards.

- **2008 Standards Prognosis** – this summarizes the thinking of key stakeholders on which measures are most likely to be considered for the 2008 revision of the building efficiency standards. This prognosis provides guidance of research topics that would have near term code impact.
- **Research Needs for California Title 24 Lighting Standards** – this details the specific research topics that can support the development of the 2008 and 2011 building energy efficiency standards. The topics of this research can be characterized in the following categories:
    - Behavior and market analysis of how people design and use lighting (design and usage baselines).
    - Basic research of human wants and needs for light and the impact of light on humans.
    - Characterization of technology, market acceptance, costing etc. of pre-existing technologies (LEDs, skylight louvers, digital lighting controls, fluorescent lamp cathodes, etc.).
- **Fundamental Lighting Research Needs** – this details research topics that require a more basic exploration of the fundamental principles underlining our current understanding of lighting. While these issues may be a long-term research they will have profound effect on human productivity, health and technological development in the future. This will no doubt influence future codes and standards which will balance the needs for energy savings with human health, societal needs and technological barriers. The topics of this research are characterized in the following categories:
    - Human vision and perception
    - Materials research

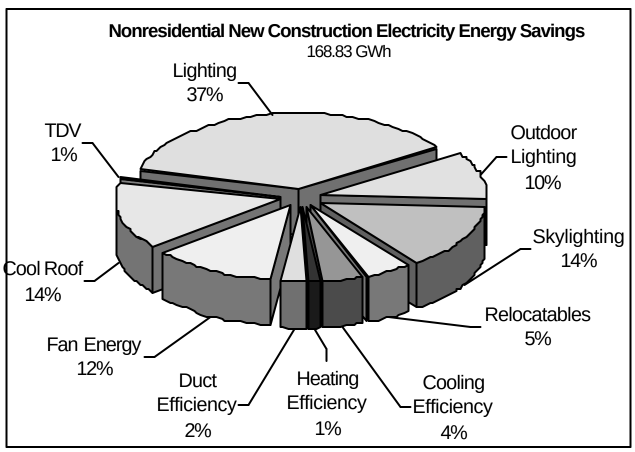
2. 2005 CODE CHANGE REVIEW AND REMAINING ISSUES

A review of the changes made to the 2005 Title 24 standards and their potential impacts on energy efficiency in the state of California provides insight into the priorities for the future round of code changes. In addition, a recounting of the lighting efficiency issues considered but not resolved in time for adoption into the 2005 standards indicates area in need of research that can directly affect energy codes.

2.1 NONRESIDENTIAL LIGHTING

2.1.1 Summary of Adopted Nonresidential Measures

Indoor lighting, outdoor lighting and daylighting measures account for 61% of the 169 GWh/yr savings due to non-residential new construction measures adopted into the 2005 Title 24 standards (Figure 2)[2]. For nonresidential alterations, the fraction of energy savings in the new code due to lighting measures are even higher; roughly 85% of the 178 GWh/yr savings for nonresidential alterations is due to lighting efficiency measures (Figure 2). Combined with a 31% and 47% share of the predicted electrical demand savings (Figure 3) for commercial new construction and alterations respectively, lighting and daylighting measures are indeed one of the most significant changes proposed in the 2005 standards.[2]



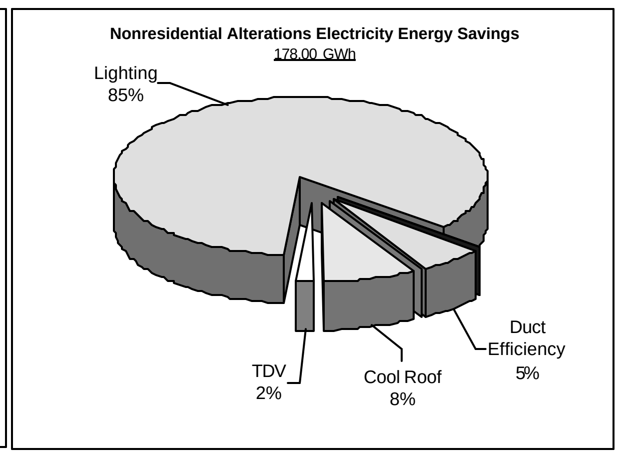
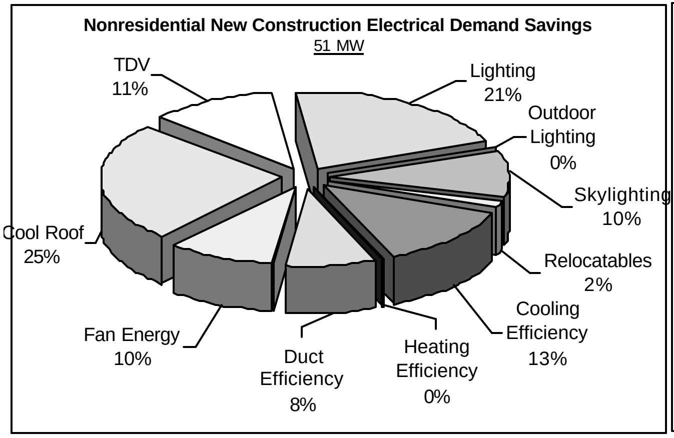


Figure 2: Projected Energy Savings from Nonresidential Measures in 2005 Title 24

[2] *"PG&E Codes and Standards Enhancement Initiatives Final Report for 2005 Title 24"*, PG&E, prepared by The Heschong Mahone Group, Inc., March, 2004



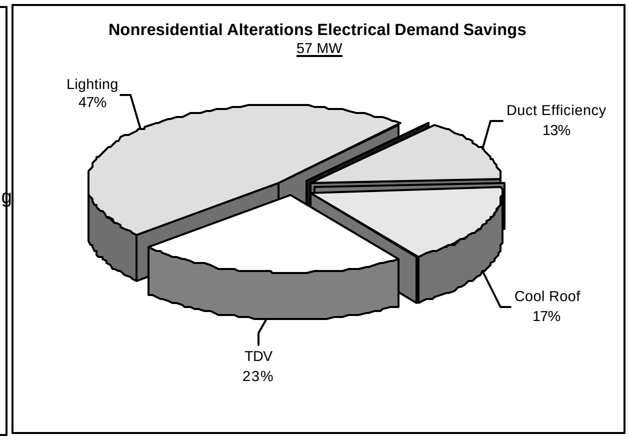


Figure 3: Projected Demand Savings from Nonresidential Measures in 2005 Title 24

Some of the more significant changes involved revising the allowable Lighting Power Densities (LPDs) in both the whole building and area category methods. Changes were also made to the LPD allocations in the tailored lighting method. The 2005 Standards also promote the use of daylighting and daylighting controls in large commercial spaces such as warehouses and retail by introducing requirements for skylights and photocontrols. The standards also encourage bi-level or multi-level lighting controls and provide credits for automated bi-level controls in various space types. Load shedding is encouraged in the standards through credits for manual dimming with load control. Perhaps the most strategic change is the addition of unconditioned spaces such as parking lots and other outdoor lighting applications to the list of spaces governed by Title 24.

2.1.2 Outstanding Issues with Adopted Nonresidential Measures

While some of the measures recommended for the code change were accepted by all the stakeholders without any significant concerns, a number of measures proved controversial and there were difficulties crafting code provisions that were supportable and enforceable. The issue of appropriate LPDs for space types such as classrooms or retail, and the regulation of certain lighting system types such as task lighting, proved controversial and difficult to resolve.

Of particular interest were the changes made to the tailored lighting method, especially involving the appropriateness of, or need for, the LPD provisions for high-end retail applications. A review of the nonresidential new construction database indicates that 46% of existing retail spaces would not comply with the 2005 Title 24 requirements for LPDs to be less than 1.7 W/sf for prescriptive compliance. In addition, it was found that in those spaces with high LPD's, most of the LPD was from fluorescent or high wattage metal halide lighting. This is a surprising result since popular belief maintains that high LPD's in retail lighting are due to halogen or incandescent light sources. Nonetheless, recent developments in miniaturized ceramic metal halide spotlighting technology may have the potential to reduce the justification for extra allowances for high-end retail, reducing dependence on incandescent sources. See Section 4.2.3 for a more detailed discussion of this issue.

The issue of verifiable energy savings from various lighting controls such as occupancy sensors and photocontrols was also brought up during the code change deliberations. One of the code change proposals suggested the elimination of any lighting control credits and making controls mandatory as is done in the ASHRAE 90.1-2001 and the IECC (International Energy Conservation Code) energy codes. The decision was made to retain the Power Adjustment Factors (PAF) as they help encourage controls that save energy but are not appropriate or cost effective in all applications. Another proposal suggested granting a PAF for dimming ballasts in order to encourage their adoption in the market, independent of their energy savings. This PAF for dimming ballasts with manual controls is available only if the ballast is also on a demand responsive control. However, this 'demand responsive control' was left undefined.

2.1.3 Dropped Nonresidential Measures

A number of the code change proposals were dropped due to either lack of sufficient information, a poor cost-benefit ratio, un-verifiable savings, or lack of enforceability. Some of these measures included –

- Redefine daylight zone for sidelighting
- Eliminate lighting control credits
- Provide power adjustment factors (PAF) for bi-level controls in stairwells
- Separate code section for lighting in multifamily buildings

Some of these measures may warrant a revisit in the next round of standards development.

2.2 RESIDENTIAL LIGHTING

2.2.1 Summary of Adopted Residential Measures

Residential lighting measures incorporated in the 2005 Title 24 standards account for a large share of the predicted electrical energy savings from the 2005 Title 24 residential lighting code changes.

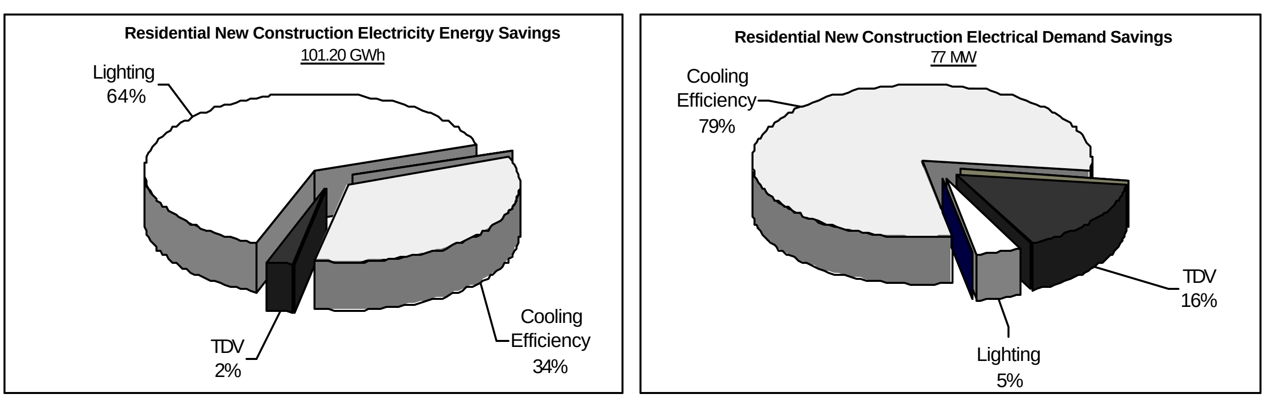


Figure 4: Energy and Demand Savings from Residential New Construction Measures in 2005 Title 24

Electrical energy savings from lighting measures account for 64% of the predicted savings from residential new construction code changes implemented in the 2005 Title 24 Standards. Lighting measures also account for 5% of the predicted demand savings from residential new construction lighting code changes.

Perhaps the most significant change in the 2005 residential standards is the requirement for high efficacy hardwired lighting in residential kitchens, and the requirement for either high efficacy hardwired lighting or lighting control devices such as dimmers and occupancy sensors to reduce lighting power consumption in other rooms.

Residential outdoor lighting is required either to use high efficacy luminaires or to be controlled by a motion sensor with integral photosensor.

2.2.2 Outstanding Issues with Adopted Residential Measures

As discussed above, the most significant change in the 2005 residential lighting standards came in the form of requirements for high-efficacy fixtures in kitchens, bathrooms, and several other spaces. Lighting fixtures attached to the exterior of residential buildings and for large parking lots are also required to use high efficiency sources. At present, the least-cost technology for achieving >40 lm/W in residential indoor fixtures is fluorescent lamps, of which compact fluorescent lamps (CFLs) are the most common.

In developing the standards for high efficiency residential lighting, two options were considered:

1) High efficiency fixtures had to contain high efficacy lamps and this could include screw-in CFLs or

2) High efficacy fixtures had to have a hard wired ballast and a pin-based CFL.

Proponents of screw-in CFLs made note of the popularity of screw-in CFLs, and their low cost and flexibility (one can increase light levels by screwing in a different wattage CFL). Proponents of pin-based CFLs declared that screw-in CFLs were not persistent and that once the screw-in CFL burnt out that it would be replaced with an incandescent lamp. Both sides agreed that the energy savings and cost of equipment for both were very cost-effective when compared to an incandescent base case. Even though there was little data to make a decision on the persistence of screw-in CFLs, it intuitively made sense to most of the stakeholders that pin-based CFLs would be more persistent, and thus, they were required.

To give greater flexibility when CFLs are not desired or feasible, dimmers or occupancy sensors were deemed to be a reasonable energy trade-off for high efficacy sources. Concerns were raised whether automated lighting controls will result in actual verifiable and persistent savings with some arguing that these lighting controls would not be promoted through the standards requirements and others arguing for making the controls mandatory in certain applications. There is little data to indicate the magnitude of savings from dimmers and occupancy sensors in residential spaces. In the final judgment, it was decided that the savings were likely to be real enough to justify use of the controls, but the need for better data remains.

In order to encourage builders to implement the high-efficacy lighting requirements in the 2005 Title 24 standards, the California Energy Commission (Commission) has provided early compliance credits for those builders who install the 2005 lighting requirements before the requirements actually go into effect in October 2005. The temporary credit allows a builder to do a trade-off between increased efficiency of the lighting measures and reduced efficiency of other building measures. It remains to be seen how this early compliance credit is used and the effect of this trade-off on the other measures.

2.2.3 Dropped Residential Measures

A number of the code change proposals were dropped due to either lack of sufficient information, a poor cost-benefit ratio, un-verifiable savings, or lack of enforceability. Some of these measures included –

- Mandate use of occupancy sensors in some residential spaces
- Develop prescriptive lighting power densities for residential spaces
- Develop an energy budget for lighting in residential spaces similar to those for commercial spaces (LPDs)
- Require electronic ballasts in all residential fixtures (currently required for fixtures >13 Watts)
- Regulate landscape lighting efficacy and controls

A number of these ideas may warrant a revisit in the next round of standards development.

2.3 OUTDOOR LIGHTING

One of the biggest changes introduced in the 2005 standards is a significant expansion of efficiency requirements for outdoor lighting. These changes apply to both residential and commercial spaces.

2.3.1 Summary of Adopted Outdoor Lighting Measures

The 2005 standards will for the first time create "lighting zones" in the state that will govern the maximum allowable LPDs for various nonresidential outdoor lighting applications such as façade lighting, service stations, outdoor sales lots, and outdoor dining among others (§147). This set of requirements recognizes that different light levels are appropriate for different tasks and upon different contexts or surroundings. Thus a fairly high lighting power density is allowed for facades in high population density environments and no façade lighting is allowed at all in the middle of a state park.

Prior to the 2005 Title 24 standards, there were limited outdoor lighting efficacy and controls requirements. Nonresidential outdoor lighting greater than 100 W/lamp was required to have a luminous efficacy at least 60 lm/W, or be controlled by a motion sensor (§130(c)). In addition, the standards required that all nonresidential exterior lighting be controlled by a photocell or an astronomical timeclock (§131(f)). In the past, only outdoor lighting that was on the same electrical service as a conditioned space was regulated.

The 2005 Title 24 standards apply the above requirements even if outdoor lighting is on a separate electrical service. The 2005 standards have a new section (§132) for nonresidential outdoor lighting that combined the previous requirements with additional electrical control and glare control requirements. Outdoor lighting will have a new requirement for multi-level switching similar to the multi-level switching requirements currently required for interior lighting. Outdoor lighting with lamps greater than 175 Watts shall be designed to be cut-off – so the light is sent to the target and is not wasted and causing glare.

The new standards also require that residential outdoor lighting, regardless of lamp wattage, must be high efficacy or controlled with a combined motion sensor/photocell.

This first generation of outdoor lighting standards represent a first step in trying to balance social needs for outdoor lighting with increasing concerns about the growing energy use and environmental impacts of nighttime lighting.

2.3.2 Outstanding Issues with Adopted Outdoor Lighting Measures

The above mentioned comprehensive outdoor lighting requirements are a new addition to Title 24 in 2005, and as with many new changes, there was significant debate on the intent, nature, and enforceability of the proposed measures among the various stakeholders in the code change process. One of the main arguments was over the definition of the "lighting zones," and whether local jurisdictions could adequately enforce the lighting zone regulations. The issue of appropriate baseline for the lighting zones and allowable LPDs generated debate, as some in the industry viewed the requirements as being too stringent, while others in the environmental field viewed the requirements as too lax. There is concern among some environmental and energy efficiency proponents that in the short run, the outdoor lighting standards may be allowing generous lighting levels in most lighting zones due to their use of IES recommended LPDs. These are viewed to be higher than current lighting practice in some applications and lighting zones. Additionally, energy efficiency proponents feel that the lighting power allocations in the new standards are higher due to safety and security adders that were included for outdoor lighting. There is currently no state or national standard for appropriate illumination levels for safety and security in outdoor spaces, and energy efficiency proponents feel that by assuming the illumination levels required are the same across all lighting zones (regardless of ambient lighting conditions) the standards may lead to substantial increase in outdoor lighting energy use.

One of the other significant issues is how the residential and non-residential requirements for outdoor lighting relate to each other.

2.3.3 Dropped Outdoor Lighting Measures

A number of outdoor lighting applications were dropped from consideration due to either lack of sufficient information about their current status, the complexity of design issues involved, or lack of time to consider them. Some of these application types included –

- Power limits on signs
    - Unfiltered signs
    - Animated signs
- Landscape lighting
- Sports lighting
- Industrial lighting
- Street and highway lighting

A number of these application types may warrant a revisit in the next round of standards development.

3. 2008 STANDARDS PROGNOSIS

HMG conducted and attended various meetings with the California Energy Commission, utility representatives, and researchers to understand their perspectives on what code changes could be proposed for the next round of Title 24 changes in 2008. These meetings were extremely useful for the participants to understand each others perspectives, and to develop a matrix of proposed measures that may enjoy broad support. A brief summary of these meetings follows:

3.1 CALIFORNIA ENERGY COMMISSION STAFF PERSPECTIVE

HMG conducted meetings with the Commission and PIER representatives to discuss the Energy Commission's priorities for 2008 Title 24 standards. The first meeting was very useful, and the participants expressed a desire to continue discussions, and thus a second face-to-face meeting was conducted. At these meetings, HMG presented the key findings of the PIER LRP projects, and discussed the code potential for the products which are closest to code-ready. However, most of the focus and time was spent on understanding the Energy Commission's needs for future rounds of Title 24 changes.

The Commission staff is interested in researching the impacts of the 2005 standards before tackling the next round of 2008 changes. The 2005 standards have made some significant advancement to the lighting requirements for both residential and commercial buildings, and staff feels it would be prudent to seek feedback on market reaction to this round of changes before undertaking more changes.

Overall, the Commission staff felt that the LPDs set out in Title 24 2005 are close to the technology threshold, and barring any significant improvements in lighting technologies (specifically lamps and ballasts), there is not likely to be a significant opportunity to reduce LPDs further.

Lighting controls, on the other hand, are viewed as the likely next frontier in the development of Title 24 codes. It is understood that significant energy savings can be achieved with a variety of control types.

Programmable controls are a whole new area where the standards probably are not keeping up with the state-of-the art in controls technology or applications. Future standards will need to acknowledge smarter control functions; however, regulating their use will need some creative solutions. For example, multi-scene controls could be regulated by the code, but it would need new thinking and language to ensure that the reprogrammable features do not defeat the code-intended control strategies, since these controls are basically software and not hardware (like traditional switches). For example, it would be fairly easy to reprogram the control device in a residence so it controls both the high-efficacy and non-high-efficacy circuits, while Title 24 currently requires these two circuits to be controlled separately by two switches.

The Commission staff anticipates continued problems with electricity reliability in the state of California, and expects demand responsive technologies to play a bigger role in the near future. The Commission/PIER program has therefore taken the lead in the creation of the Demand Response Research Center. The Center will coordinate development of demand responsive technologies.

A more detailed summary of staff priorities for lighting standards is included in Section 4 of this report.

3.2 CALIFORNIA UTILITY STAFF PERSPECTIVE

A meeting was held at PG&E's offices on May 13th where representatives from all the major California utilities, the Commission, and several energy efficiency consultants met to discuss potential measures for the 2008 round of Title 24 code changes.

The meeting was relatively informal, consisting of presentations on proposed additions to the 2008 standards by representatives of the PIER program, Commission codes and standards staff, and consultants for the PG&E and SCE codes and standards programs. As part of this presentation, the consultants were asked to present what they consider to be the top 3 to 5 important potential measures and to rank their attributes. Table 1 shows the lighting related measures and the rating by the consultant proposing the measure along the following attributes:

1. Economic feasibility (a best guess of benefit/cost ratio, demand reduction potential)
2. Technical feasibility (reliability, performance with respect to intended use)
3. Industry and market readiness (availability, infrastructure required to support intended use)
4. Code enforceability (capability of building officials, acceptance testing requirements, third-party inspection requirements, inspector capability and experience with technology, time needs for field inspection)
5. CASE study development effort (market research, economic analysis, model development, availability of market data)

Proposer	Code Enhancement Topic	Economic Feasibilty	Technical Feasibility	Industry and Market Readiness	Code Enforce-ability	Develop-ment Effort	Total Score
HMG, CEC C&S	Update Outdoor Lighting	6	7	3	5	5	***26***
AEC, CEC C&S	Update Outdoor Lighting	6	6	6	6	4	***28***
CEC C&S	Top Lighting - Smaller Buildings / Lower Ceilings						***n/a***
HMG	Tailored Lighting Revisions	6	5	4	7	5	***27***
CEC C&S	Acceptance Requirements / Third Party						***n/a***
HMG	Updates to Treatment of Sidelighting	7	6	6	5	5	***29***
Gabel	Premium T8 Technology as Basis for New LPDs	7	7	5	5	7	***31***
Gabel	Lighting Controls, Nonres Performance Approach	5	5	7	7	5	***29***

Table 1: May 13th Workshop – Proposing consultant evaluation of potential 2008 T-24 lighting measures

The ratings were on a scale of 1 to 7, where 7 reflects the most return in energy savings and the least amount of effort and disruption to the existing market. Measures that were proposed only by the Commission did not have such attribute ratings. Since the consultants were asked to present on what they considered good ideas, the attributes are fairly high in most categories. Though, this rating is very subjective, the low ratings for industry and market readiness indicate some stakeholder opposition to outdoor lighting requirements and eliminating or further scaling back of the tailored lighting provisions.

Code Enhancement Topic	Workshop Participant Votes	Short Description / Comments
Update Outdoor Lighting	11	Revisit and update the requirements for outdoor signs and lighting, organized industry opposition
Top Lighting - Smaller Buildings / Lower Ceilings	7	Expand scope (building area, ceiling heights) where skylights are required.
Tailored Lighting Revisions	7	Would simplify lighting enforcement, but would impact lighting design
Acceptance Requirements / Third Party	5	study implementation--will these need to change?
Updates to Treatment of Sidelighting	5	Large research effort, potentially high reward
Premium T8 Technology as Basis for New LPDs	2	Develop cost-effectiveness data on highest efficiency T8 lamp & ballast technology
Lighting Controls, Nonres Performance Approach		Develop hourly control credits for the performance approach based on best available monitoring data

Table 2: May 13th Workshop – Participant ranking and description of potential 2008 T-24 lighting measures

Table 2 shows the ranking of the measures at the May 13th workshop. It should be noted that this "beauty contest" approach to ranking the measures does not reflect a rigorous analysis of the cost/benefit of measures or the likely statewide energy impact of the measures. However, it does reflect the educated opinions of energy experts in California and the following key results came out of the meeting:

- Outdoor lighting is a new area of code regulation and a significant amount of additional savings are likely from refining outdoor lighting codes.
- Treating daylighting as a required energy measure is also a new area of regulation and will likely yield more savings as the requirements are fine-tuned. An interesting outcome of the voting was that Commission staff was more interested in expanding the scope of the 2005 Title 24 toplighting requirements whereas utility staff was more interested in developing requirements for sidelighting.
- Residential lighting measures were not on the list of high priority measures. This is likely due to the perception that the 2005 standards were very aggressive in terms of residential lighting and it might be best to evaluate how this affects building practice before embarking on further residential lighting requirements.

4. RESEARCH NEEDS FOR CALIFORNIA TITLE 24 LIGHTING STANDARDS

In general, energy codes are written to eliminate poor design practice and are not intended to require extraordinary designs or products that have not yet gained market acceptance or products that are not yet cost-effective. This is in marked contrast to the scope of energy efficiency research and development focused on inventing a novel technology that may have no market experience, no developed costs, and no track record of reliability. When these novel products are introduced into the market and demonstrate sustained energy savings and market feasibility, they can end up in the energy codes. However, this is a medium term result that extends over several code development cycles. Thus in general, research that supports energy codes is focused around the following topics:

- Characterizing the energy performance of pre-existing efficient products or systems already in the market.
- Comparing the life cycle energy cost savings to the current market incremental cost of the product and in some cases its long term maintenance costs. This analysis is not based upon some hypothesized cost of the product once the code has generated sufficient economies of scale.
- Evaluating the market feasibility of the product or practice. Is the product reliable and will it save energy reliably over the long term? How does it impact other building components and the overall energy efficiency of the building?
- Surveying market acceptance of the product. Does the product impact the comfort, aesthetics or use of the building?

It should be noted that there are different levels of certainty required for different types of energy code measures. Technologies that are reasonably developed, but not applicable or not cost-effective in all cases, are usually incorporated into the codes as a *compliance credit*. One can use the technology to offset increased energy use by another building component. Compliance credits are essentially voluntary as the standard code compliance building is not required to use the technology. Technologies that are shown to be cost-effective in almost all circumstances and have minimal problems being incorporated into the rest of the building design can be incorporated as a *prescriptive requirement*. The prescriptive requirement defines what the baseline condition of a minimally code compliant building is. In the few cases that the prescriptive requirement is not feasible or not desired for the building, one can use the performance approach and substitute the technology with a building design that uses no more than the prescriptively required technologies. Technologies, which are proven to always be feasible, cost-effective, and reliable, can be incorporated into the standards as a *mandatory* requirement. Thus, the burden of proof of the feasibility of measures in the standards varies from moderate for compliance credits to the very stringent for mandatory requirements.

4.1 RESIDENTIAL RESEARCH NEEDS

4.1.1 Residential Hardwired Lighting

The 2005 standards have made a significant change to the residential hardwired lighting requirements as discussed earlier in this report. While the expected energy efficiency impacts of the these changes were carefully estimated, the issues of customer acceptance and market availability need further research to understand the impact of the 2005 Title 24 changes on the market in the coming years. In addition, we need better and more up-to-date data on lighting usage patterns to fully quantify the benefits of the standards changes.

4.1.1.1 Updated Residential Lighting Baseline

a. Code question – What is the magnitude and variability in residential lighting energy use in California?

In the Commission's California Lighting Baseline study conducted in 1996, analysis of residential lighting energy consumption and demand was conducted using 1994 monitoring data gathered by Southern California Edison. Although there have been some resources devoted collecting new field data, there has not been a focused effort to update this study. The Residential Appliance Saturation Study conducted in 2003 generated an inventory of various appliances in residences including light fixtures. However, this study could not disentangle the indoor lighting loads from other plug loads and ceiling and attic fans. This study also did not generate time-of-use or schedules of operation of the light fixtures in the different spaces. A separate study being currently conducted by KEMA-XENERGY is conducting long term monitoring of a sample of 300 houses spread across California where they are monitoring the hours of usage of CFL lamps in various residential spaces. KEMA-XENERGY is also conducting a detailed inventory of the light fixtures in the residence, to identify the connected lighting load in the different houses.

A study that combines results and observations from these and similar studies would greatly benefit the utilities, Commission staff, and researchers to identify potential for lighting energy savings in residences. This study could potentially be similar to the 1996 California Lighting Baseline study that essentially combined results from three separate studies to develop a baseline of lighting energy usage by space in residences.

Such an update should be done prior to the effective date of the 2005 residential lighting standards, to describe progress made in the past ten years, and then the study should be updated once again in late 2006. This would allow for a before and after comparison of the effects of the new standards, and would help to inform any adjustments that should be adopted into the 2008 standards.

Potential research approaches

- Update and/or revise the California Lighting Model to describe statewide magnitudes and patterns of lighting energy consumption in residences.

4.1.1.2 Consumer acceptance of CFLs

a. Code question – Is there adequate market availability and consumer acceptance of pin-based lamps/ballasts in California?

Unlike screw-based CFLs which have integral ballasts, pin-based lamps require separate ballasts. Typically the ballast will power a specific wattage of pin-based lamp, or a limited range of lamp wattages and lamp numbers. Thus, when the average residential customer decides to buy a replacement lamp, he/she will have to match the lamp to the wattage range of the installed ballast. The limited range of wattages for a given ballast restricts the ability of the occupant to increase or decrease light output from the fixture by swapping out the lamp with a different wattage, as they can do with most screw-based incandescent lamps.

Further, pin-based CFL lamps and lamp holders are designed with an arrangement of flanges that prevent lamps of the wrong wattage being installed in any given fixture. Certain types of linear and circline pin-based lamp (linear T12, T8, T5, and circline T8 and T5 lamps) are already sold in the residential market, and many customers are familiar with the idea that the wattage is marked on the fixture and they must replace the lamp with one of the same wattage. Nevertheless, residential customers not previously used to pin-based fixtures may be confused about why they can't fit a certain lamp into an existing lamp holder. Preliminary studies conducted by NRDC in 2004 suggest that some manufacturers have proprietary pin configurations that allow lamps and ballasts from only the said manufacturer to work together. Such a proprietary approach will further add to the confusion of the residential consumer.

The ENERGY STAR® program has been investigating the possibility of requiring a common lamp base that will work with multiple wattage lamps which would allow more flexibility in CFL luminaires for the past couple of years. A couple of manufacturers currently sell lamp bases that can accept different wattage lamps; however there is currently no standard (such as ANSI) that governs such lamp bases. Further, these lamp bases are still dependant on the ballast accepting the different lamp wattages.

Pin-based CFL lamps (without the ballast) also cost more than comparable screw-based CFL lamps (including ballasts) currently available in the market. Partly this is due to the heavy promotion of screw-based CFL lamps by utility energy efficiency programs in the state of California. There are no comparable programs for pin-based CFL lamps for residential applications.

Potential research approaches –

- Survey of existing pin-based lamp penetration in the market and the impact of 2005 Title 24 on market penetration of pin-based CFLs
- Statewide customer survey to gauge understanding of lamp/ballast restrictions and determine whether a need for consistent labeling exists.
- Survey of ballast and lamp costs for pin-based CFLs in the California market

b. Code question – How can the quality and reliability of pin-based CFLs being sold in the California market be assured?

Pin-based lamps are extensively tested by the major manufacturers to ensure that they meet the manufacturer's own quality standards, and there may be a high degree of commonality between the standards of different manufacturers. Nevertheless, there is no objective third-party testing procedure for pin-based lamps that compares with the EPA's ENERGY STAR® rating and testing procedure for screw-based CFLs. Recent test data has indicated problems with premature lamp failure, with inadequate light output, and similar reliability problems that will be a barrier to consumer acceptance. There is a need for a uniform standard or rating procedure for pin-based CFLs especially in light of the 2005 Title 24 regulations that will require high-efficacy pin-based CFLs in residences.

Potential research approaches –

- Survey existing testing data from various manufacturers and identify commonalities and differences in lamp performance characteristics
- Generate experimental data from National Voluntary Laboratory Accreditation Program (NVLAP) accredited laboratories on existing pin-based CFL lamps.
- Generate uniform standards or rating procedures for pin-based CFLs in collaboration with the manufacturers and ENERGY STAR®

c. Code question – What is the persistence of screw-based and pin-based CFLs in residential lighting applications?

The 2005 Title 24 residential lighting requirements do not allow screw-based CFLs to qualify as required high-efficacy sources. This is due to the worry that users will eventually replace the screw-based CFLs with incandescent lamps once the CFLs burn out, or once the building permit is issued.

On the other hand, the California utilities have been actively promoting screw-based CFLs in the commercial and residential market with increasing success in the past few years. Retail incentives provided by utilities and others have reduced the retail price of screw-based CFLs to around $1.50 per lamp, although the price without incentives would be higher than this.

The Evaluation report of the 2002 Statewide Crosscutting Residential Lighting Program collected data on the increase in sales of CFLs and showed that the combination of the energy crisis, conservation programs by utilities, Flex Your Power campaign, and the ENERGY STAR® program resulted in significant increase in awareness and sales of screw-in CFLs in the state. Roughly 56% of the 1,001 California residents polled reported to have used at least one screw-based CFL in the past year, and a majority of these respondents were first time users. Among the CFL users, the satisfaction levels were high, with only about 13% of the users being slightly or very dissatisfied with the CFL performance in 2003. However, the percentage of people that were very satisfied with CFLs decreased slightly from about 62% in 2001 to about 58% in 2003 (Figure 5). The main complaint in 2001 was that the bulbs were not bright enough, compared to light quality in 2003.

At the same time awareness and use of pin-based CFL fixtures was very low, with about 4% of the respondents in 2001 reporting the use of pin-based CFL fixtures and 2% of respondents in 2003.

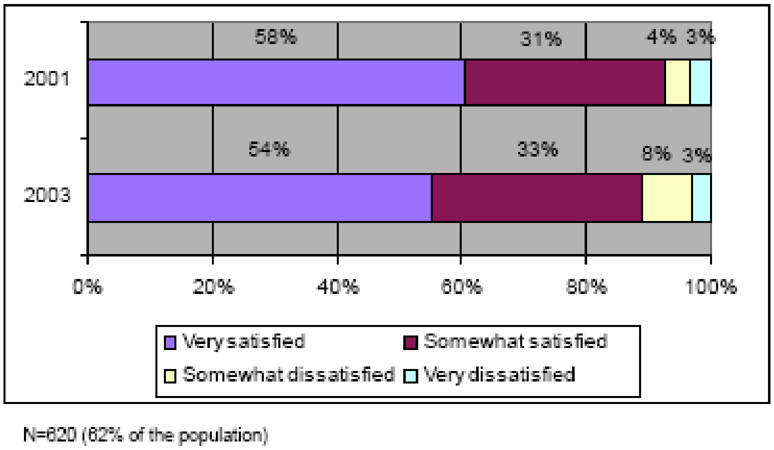


Figure 5: Satisfaction with CFLs in residential applications – 2002 Statewide Crosscutting Residential Lighting Program

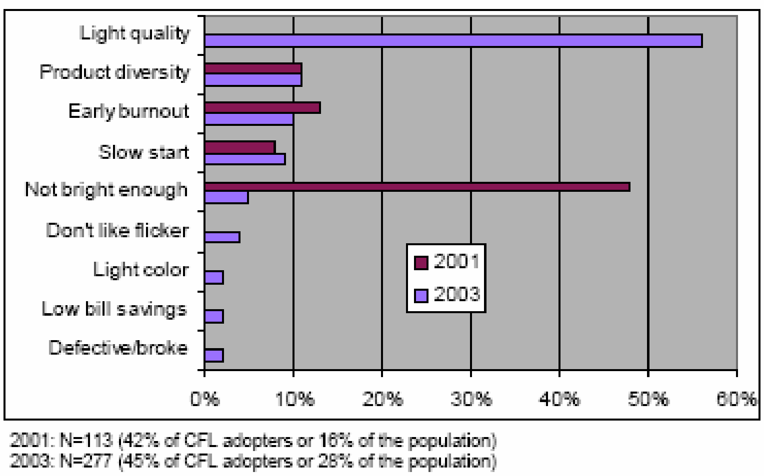


Figure 6: Reasons for dissatisfaction with CFLs – 2002 Statewide Crosscutting Residential Lighting Program

Some of the main reasons for dissatisfaction with CFLs included light quality, product diversity and early burnouts.

Similar findings were published recently by a study conducted for NEEA. The Market Progress Evaluation Report of NEEA's residential lighting programs submitted in August this year tracked changing consumer awareness, purchase barriers and satisfaction with ENERGY STAR® CFLs in the NEEA territory between 2001 and 2003. The study found a fairly high satisfaction rate with screw-based CFLs with roughly 80% of the surveyed residential consumers reporting that they were either "Satisfied" or "Very Satisfied" with the CFLs. However, it observed a similar trend as the 2002 California study mentioned above in that the relative percentage of people who were "Very Satisfied" decreased between 2001 and 2003, however number of people who were "Satisfied" increased in the same period. Overall, the combined total of these two responses increased from 2001 to 2003. The study also found that those who were unhappy with the CFLs cited poor lighting quality, lamp size and cost as the main barriers to adoption.

A paper recently submitted by Richard Fasey et al. at the 2004 ACEEE summer conference provided an overview of the state of ENERGY STAR® screw-based lamps and pin-based fixtures in the market. The paper reports that builder and consumer resistance, limited availability, and complex lamp/ballast combination requirements have resulted in very slow growth of pin-based CFL fixtures. Further it notes that consumers will be less likely to tolerate pin-based fixture failure than screw-based CFL lamp failure due to the higher cost and lack of availability of the pin based fixtures. The paper presented some preliminary results from programs in Vermont and Massachusetts where lamp and fixture quality concerns and early burnouts is causing increasing concern among program administrators. Lack of uniform standards for pin based CFLs was reported as one the reasons for the heightened concern among program administrators

All the studies point to a very dynamic market place where the perceptions about CFLs, their persistence and the availability are changing. In light of the 2005 Title 24 requirements for pin-based CFLs, a study of the current California preferences for CFLs as a whole and type of CFLs in particular is needed to partly understand how the market could react to the 2005 standards. A study could be conducted before the standards go into effect, and can be followed up a year after the codes go into effect to identify and changes in customer preferences and market acceptance of screw-based and pin-based CFLs. Further, such a study could also provide information on whether a greater choice in type of CFL lamps and bases would provide greater penetration of CFLs in the market and greater compliance with codes.

Potential research approaches –

- Statewide survey of comparative customer satisfaction with screw-based and pin-based CFLs in residential lighting applications
- Long-term M&V of utility CFL programs to identify persistence of screw-based and pin-based CFLs in residential applications

4.1.1.3 Effectiveness of existing residential lighting controls

The 2005 Title 24 standards support a number of residential lighting controls, including occupancy control, time switches, and photocontrols through code compliance requirements. Before regulation can be expanded to more spaces and control types, there needs to be good data on the effectiveness of current controls products in the residential market to ensure that the controls measures are actually achieving the intended energy savings.

a. Code question - Do the automatic lighting controls currently promoted by Title 24 perform adequately per code intent?

At the time the 2005 controls requirements were adopted, there was very little field data to describe consumer behavior with many of these controls. This is especially true for occupancy sensors in bathrooms in private homes. Answering the question of lighting controls effectiveness and actual verifiable savings would guarantee that code provisions learn from the market realities today, and are better equipped to provide reliable savings in the future. Answering the question would also help manufacturers refine their products in order to avoid any common and easily rectified product deficiencies.

Potential research approaches –

- Statewide field survey to measure existing automatic lighting controls' energy and demand savings performance
- Customer survey of satisfaction with controls features and performance
- Before/after comparison of the penetration of lighting controls in residences, prior to and following implementation of the 2005 standards changes

b. Code question – Do manual dimmers on incandescent lighting reduce energy use to levels comparable to high efficacy lighting controlled by traditional switches?

Title 24 2005 allows an exception to the requirement that residential hardwired fixtures must be high-efficacy, if dimmers are provided.

There is some evidence from studies of lighting in commercial buildings that manual dimmers reduce energy consumption compared with simple switches, but there is no evidence that this effect exists in residential buildings. A simple study could help to determine whether this exception to the high efficacy lighting requirement should be retained as an effective energy saving or demand reduction measure, or should be seen as an interim measure to ease the progression to the universal use of high efficacy luminaires. It may also be found that dimmers save a sufficient amount of energy only in certain rooms or in certain types of light fixtures. This information could be used to modify the conditions where manual dimming is an acceptable alternative to high efficacy lighting.

Potential research approaches –

- Survey customers on their use of dimmers, when and why
- Analyze patterns of monitored usage to determine whether dimmers save energy and peak demand compared to non-dimmed high efficacy luminaires for various residential spaces and applications.

4.1.1.4 Understanding consumer and builder preferences for residential lighting

The residential lighting market is different from the commercial lighting market in that the cost effectiveness and efficiency of lighting may not be the over-riding concerns when the builders or home owners install lighting systems. While encouraging energy efficiency is the goal of the Title 24 standards, it is equally critical to understand the choices, preferences, and trends in residential lighting from the perspective of builders and homeowners. Understanding their preferences will ensure that high-efficiency lighting products are tailored to their preferences, and therefore have a better chance of achieving market success.

a. Code question – What are the current trends in choice of residential lighting by builders and home owners?

It is clearly in the interest of builders to provide features that make homebuyers more likely to purchase the house, or to pay more for the house. However, it is far from clear which features are commonly perceived by builders to add value to a house, and more importantly which features are perceived by buyers to add value. These perceptions may be influenced by factors such as the demand and supply of housing, the type of buyer, and the vagaries of fashion. Many features such as the kitchen countertops and the bathroom fit-out are sometimes left unfinished by the builder to allow the buyer to choose between several standard options at purchase time.

A clear understanding of which lighting features builders feel are appropriate and cost effective will greatly help in the future development and marketing of high efficacy luminaires. It is possible (though not common at present) that luminaires could be considered as an options package rather than as an integral part of the building.

An early indication of these preferences will come through the acceptance of the early compliance credits that the Commission has made available to builders. These early compliance credits encourage builders to install the pin-based high-efficacy lamps in their residences, by allowing a limited tradeoff with other building measures.

Potential research approaches –

- Statewide survey of builders' lighting practices, preferences and beliefs
- Develop and analyze a pilot scheme of California high-efficacy lighting options packages, with feedback from buyers and builders
- Compare results to adoption of other pilot schemes including the Advanced Lighting Package from ENERGY STAR®
- Statewide survey of early compliance with 2005 Title 24 lighting requirements

4.1.1.5 Performance of CFL lamp-ballast systems

There are a number of different ways in which electronic ballasts can start CFL lamps; these range from simple instant-start procedures up to more complex programmed-start procedures. There are at least five common descriptions for different lamp starting procedures, and the details vary from one manufacturer to another.

Programmed-start ballasts can significantly extend lamp life in applications where the lamp is switched on for brief periods, as is the case with residential lighting, but some programmed-start ballasts consume more power when switched on than instant-start ballasts do. It might be possible to work with manufacturers to develop a simple specification for a ballast to ensure both high efficiency and long lamp life.

a. Code question – What is the consumer preference for lamp starting procedure?

b. Code question - What are the energy savings and lamp life implications of various lamp starting procedures?

c. Code question – Is there a need for a standard lamp starting procedure? What are the key characteristics of such a procedure?

Potential research approaches –

- Develop key performance criterion for lamp-ballast combination such as lamp life, light quality, lumen depreciation, energy savings, consumer preference etc.
- Rate various lamp starting procedures on key performance characteristics
- Collaborate with manufacturers on the development of a standard lamp starting procedure or standard operational specifications for various lamp starting procedures

4.1.1.6 Programmable controls

Lighting controls are probably the next frontier for residential lighting standards. The lighting controls industry is rapidly evolving, with more flexible controls offering 'scene' controls in a residence becoming more cost effective for high-end residential sectors. Currently, these controls are not cost-effective for mass consumption; however their availability is increasing and they may replace traditional light switches in at least a portion of the high-end residential market. It is critical to understand how such programmable controls might affect residential lighting energy consumption.

a. Code question – What is the energy efficiency potential of programmable lighting controls available currently for the residential market?

The programmable lighting controls are making a transition to the residential market from the commercial market. It is critical to understand the capabilities of these residential programmable controls in order to understand their potential impact on energy savings in the state of California.

Potential research approaches –

- Identify key performance specifications through literature review of existing programmable lighting controls for residential applications
- Identify impacts on energy savings due to programmable controls
- Collaborate with manufacturers through product development and advisory groups to ensure standard performance specifications to achieve energy savings goals of the standards

4.1.2 Lighting Power Densities for Residential Spaces

The California Energy Commission currently regulates residential hardwired lighting by requiring high-efficacy lighting in certain residential spaces. This approach of allowing only high-efficacy fixtures does not limit the number or wattage of such high-efficacy light fixtures.

An alternative approach would be instead to regulate the total wattage of fixtures installed in the residences, as some anecdotal evidence suggests that lighting use is on the increase as size of residences has increased over the past few years. The rationale for this code change would be to ensure that installed wattages of residential lighting do not exceed reasonable bounds.

On the flip side, developing lighting power density allowances for residential spaces will also enable tradeoff of the lighting measures against other building envelope and HVAC measures. This could potentially have an impact of people using less hardwired lighting in the building and trading off the energy surplus in lighting with lower performance HVAC unit or window glass.

To encourage the use of high efficacy lighting prior to the implementation of the high efficacy lighting requirements in the 2005 standards, the California Energy Commission is giving a 1.5 kBtu/sf credit for homes that have high efficacy lighting or controls that are deemed equivalent. Thus, adding high efficacy lighting before the 2005 standards take effect will potentially allow one to install a less efficient envelope, glazing, or mechanical system. While the 1.5 kBtu/sf tradeoff credit may not cause significant change to the efficiency of the HVAC system or envelope, allowing a LPD method in the future round of standards may allow bigger tradeoffs.

a. Code question – Is an LPD requirement appropriate for the residential energy code?

If LPD requirements are included into the performance method then one can trade-off low LPD's against other building features. This is a concern as in many rooms in a residence; permanently connected lighting could be eliminated and used as a trade-off against other building efficiency features. Many of the rooms can be built with no permanently connected lighting and lighting in the space could ultimately be provided through plug connected lighting: table lamps, luminaires, or plug connected suspended lighting. The 2005 standard requires that these fixtures are high efficacy or have automatic lighting controls or dimmers, but plug connected lighting is essentially unregulated. Thus, a residential lighting LPD could ultimately backfire by reducing the efficiency of non-lighting features and encouraging the use of plug connected lighting.

Potential research approaches –

- Site survey comparison of total <u>installed</u> lighting power (permanently connected lighting and plug connected lighting) in homes with little permanently connected lighting wattage to those with relatively high connected lighting wattage.
- Site survey comparison of total lighting power <u>consumption</u> (permanently connected lighting and plug connected lighting) in homes with little permanently connected lighting wattage to those with relatively high connected lighting wattage.

b. Code question – If LPD's are appropriate for the residential energy code, what are appropriate LPDs for residential spaces? What are the appropriate operational schedules?

The residential market is not monolithic in nature in terms of size of residence, quality of construction, expected 'value' of the residence, cost of residence, or the lifestyle of the residents. It may not be practical to develop appropriate LPDs that may be applicable across board. However, it should be possible to define LPDs by category of residences – low income, market value, residences for seniors, and high-end residences – in a way that could be amenable to efficiency standards.

Potential research approaches –

- Statewide survey of LPDs and lighting technologies installed in residences
  - Field survey and monitoring of existing installations
  - Interviews with residential designers, builders and home buyers
- Establish typical lighting use schedules for various residential spaces through statewide survey of lighting usage patterns

c. Code question - Can lighting energy be a tradeoff option in the performance method for residential building compliance with Title 24?

This research question is perhaps dependant on answers to the two questions above, but certainly the intent of such an option would be encourage overall building energy efficiency, even if that means lower than currently mandated lighting efficiency, or lower than currently mandated envelop or HVAC features. The risk of course is that such a tradeoff may result in a very efficient lighting system that may be used say 4 hours a day, but a less than efficient envelope or HVAC that would adversely affect building performance year-round.

Potential research approaches –

- Develop tradeoff scenarios and consequences on energy performance of the building through engineering models
- Identify builder and home buyer preferences through surveys/ interviews

4.1.3 Daylighting of Residential Buildings

a. Code question – can daylighting of key spaces in residential buildings cost-effectively reduce energy consumption and peak demand?

It is commonly accepted that skylights and clerestories in homes do not save energy; their primary purpose is providing the amenity of daylight. The reasons for this are that homes are commonly unoccupied during the day, lighting power densities are relatively low, most spaces are already receiving daylight from windows on perimeter walls and energy consumption in homes is envelope dominated so that increased fenestration will increase net energy consumption. Thus, energy codes have primarily focused on minimizing losses from skylights and clerestories rather than considering their energy savings potential in residences. However, some homeowners are purchasing skylights for their purported "energy savings" benefit. Is it possible that skylights are indeed saving energy in some residential applications? If so, what are these applications?

Lamp use profiles developed by HMG show lighting is more likely to be switched on at late-afternoon peak times in some rooms than in others. By ensuring adequate daylighting in these rooms it could be possible to reduce not only annual energy consumption but to delay the time at which lights are switched on until after the peak period. An example of a potential application might be in kitchens which are in the center of some residential buildings and in this case are poorly daylit. Kitchens are among the most intensively used residential spaces during the late afternoon peak.

Further there is growing evidence of people working from home as more employers find it useful to let employees 'telecommute' from home. The 2003 Residential Appliance Saturation Survey (RASS) shows that roughly 23% of the survey respondents spend at least 0-10 hours per week working from home, with about 6% working full time from home. This trend is anticipated to increase with higher penetration of high-speed internet access in residences allowing more people to work from home. There is increasing possibility of lighting energy use increasing during the daytime in residences. Some of this lighting energy usage could be easily off-set with daylighting and daylighting controls.

Potential research approaches –

- Identify residential spaces and applications where daylighting availability is likely to save lighting energy
- Survey in a side-by-side study, the lighting energy consumption in spaces with and without skylights and clerestories.
- Monitor before and after impacts of skylights and clerestories that are retrofitted into residential buildings on lighting energy consumption.
- Simulate the net energy impact of daylighting in homes including heating, cooling and lighting energy consumption impacts.

4.2 NONRESIDENTIAL STANDARDS

4.2.1 Code enforcement

Before one can begin to decide what new components to add to the standards, it is useful to start with the question how well are the current codes working?

- Is the code well understood and being consistently enforced?
- Are there aspects of the standards that are seen as an unreasonable burden by builders, designers, code officials etc?
- Do these opinions have a basis and could this be mitigated without reducing the energy savings from the standards?
- How do the codes compare to common prior practice i.e. are the codes saving any energy?
- Do sections of the energy codes create conflicts with other codes or design standards
- Are design standards rational and have technical basis?

a. Code question – Are California lighting energy codes well understood, and well enforced?

This question can be answered through a series of interviews, plan checks and site surveys.

Potential research approaches –

- Plan check review – see if plans are adequate reviewed for lighting compliance. This would include a sample of plans for the area category method as well as the more complex tailored method.
- Interviews with plan checkers, building inspectors, Title 24 energy consultants, and lighting designers.
- Site visits of spaces to observe what is actually installed.

b. Code question – Could California energy codes be simplified? Would this increase compliance?

The current standard is bloated with everyone's favorite measure, redundant cross references, and multiple locations for definitions and exceptions. The requirements for nonresidential buildings are interleaved with the requirements for residential homes. Multifamily crosses nonresidential and residential requirements. Efficiency tables that are also in Title 20 are also included. Tailored method adds several pages of calculations and tables.

An overhaul and edit of the standard could identify outlier requirements that create large administrative burdens without saving substantial energy. This simplicity rewrite could form the framework for the other 2008 candidate changes. If the energy standards were simply written, easy to understand and enforce, compliance would be higher and less expensive.

This question can be answered through a review of the existing California standards as well as energy codes from other jurisdictions, interviews with designers, plan checkers, and building inspectors.

Potential research approaches –

- Review existing standards for redundancy
- Interview designers, plan checkers, and building inspectors on what is confusing about the standards and how they would simplify the standards.
- Interview the designers of the standards to understand the big concepts the standards are trying to address.
- Analysis of the burden and statewide energy savings potential of various aspects of the standards.
- Test a simplified version of the standard for ease of understanding.

The resulting information could be used for a major rewrite and simplification of the standards. It may be possible to divide T-24 Standard into three standards (residential, nonresidential and multifamily) no longer than 30 pages each.

4.2.2 Lighting Controls

Lighting control technology has been evolving at a relatively fast pace. This has created new opportunities for energy efficiency in nonresidential buildings. Energy standards that stay abreast of these technology changes are able to capture additional energy savings that were not possible only a few years ago.

Lighting controls that reliably save energy go through an evolutionary process in the standards. Initially controls are encouraged through the use of a control credit. As the control gains acceptance and is found to be universally feasible, it can become a mandatory requirement.

Occupancy sensors have gone through this process. Originally, occupancy sensors were given a control credit. Since the 2001 standards, the control credits for standard occupancy sensors have been essentially eliminated. However, occupancy sensors are one way of meeting the automatic shut-off requirement. In 2001, the exemption to the automatic shut-off requirement for buildings less than 5,000 sf was eliminated since occupancy sensors are a cost-effective and reliable way to provide this feature to small buildings that cannot afford a night sweep lighting control panel.

A newer occupancy sensor application, "manual-on or bi-level occupancy sensors, is currently given a control credit. If these controls gain wide market acceptance and are shown to save even more energy reliably, then these controls may be mandatory in the future and the control credit eliminated.

4.2.2.1 Effectiveness of existing lighting controls

The Title 24 standards for lighting in commercial buildings continue to promote the use of automated lighting controls such as occupancy sensors, photocontrols, timers etc. through mandatory measures and power adjustment factor credits. There are many in the energy efficiency field who believe that controls should be made mandatory in most applications. However, there are also those in the energy efficiency field who believe that automated controls may not always be the best approach to saving lighting energy in all applications. A classic example is lighting energy savings in classrooms, where some have claimed that teachers can save more energy through manual switching than through automated occupancy controls.

The standards award power adjustment factors (PAFs) for a few automatic controls which are not generally applicable, but which are judged worthwhile. Generally, the PAF is set conservatively, so the energy savings fraction should exceed the additional allowable connected lighting power in most cases. This is an important assumption that should be verified through field research.

a. Code question - Do lighting controls save energy as expected in commercial buildings?

Answering this question through field research would help to guarantee that future lighting control requirements and/or credits are based on the market realities today, and are more likely to provide reliable savings in the future.

Results from such a study would also help manufacturers refine their products in order to avoid any common and easily rectified product deficiencies.

Potential research approaches –

- Field Survey - statewide monitoring of existing controls performance in a representative sample of newly constructed buildings
- Comparative study of energy savings from automated controls vs. manual controls in classrooms, conference rooms, hotel hallways, and other spaces using automatic control types encouraged by Title 24
- Customer survey to gauge satisfaction with controls

b. Code question – Do some lighting controls save energy so consistently and have little drawbacks that they should be mandatory?

This question tries to determine whether the control is ready for the next stage of its applications in codes. This task has to make sure that the measure is well accepted by the design community, it saves energy reliably, and does not have any applications where another technology is really better suited for saving energy or for meeting occupant needs or desires.

Potential research approaches –

- Field Survey - statewide monitoring of existing controls performance in a representative sample of newly constructed buildings

- Occupant interview – interview occupants on non-energy impacts of the control
- Interviews with building designers on where control is applicable and where control conflicts with building operation or performance.
- Cost-benefit analysis of controls in a range of applications

c. Code question – How can we improve energy savings and demand impacts from lighting controls through future Title 24 standards enhancements?

Potential research approaches –

- Monitor space usage patterns to identify operational schedules in various space types where controls could be potentially used
- Develop hourly control credit schedules for lighting controls to be used with time dependent valuation (TDV) performance trade-offs.

4.2.2.2 Toplighting (daylighting) requirements

The 2005 Title 24 standards introduced a mandatory requirement that multi-level photocontrols or multi-level astronomical time switches be used to control electric lighting whenever the daylit zone under skylights in a room exceeded 2,500 sf. The option for the astronomical time switch (time clock) was added because most electrical designers and contractors are more familiar with time clocks than photocontrols. It was felt that adding this flexibility would help ease the transition in 2005 for automatic daylighting controls. However, it is thought that astronomical time clocks will not save as much energy as a photocontrol. In the 2005 standards, a Power Adjustment Factor is available for photocontrols under skylights to help encourage their use. This PAF is based on the additional savings yielded from a photocontrol as compared to an astronomical time clock control.

If it is found that by the time of the 2008 standards adoption, that photocontrols under skylights are well accepted, understood, and providing reliable energy savings and that indeed the astronomical time switch is saving substantially less energy, it would be a natural progression of the standard to eliminate the astronomical time switch option and remove the power adjustment factor credit for photocontrols. Photocontrols would be a mandatory requirement without an exception when the daylit area under skylights exceeds 2,500 sf.

a. Code question – Are photocontrols sufficiently accepted in the market and do they save sufficiently more energy than astronomical time clocks that the astronomical time clock alternative to photocontrols are no longer needed for daylight harvesting under skylights?

Potential research approaches –

- Market survey of electrical engineers and electrical contractors on their comfort with designing or installing photocontrol systems

- Site survey of relative energy savings of photocontrols versus astronomical time clocks for daylight harvesting under skylights.

In the 2005 updates to the Title 24 energy efficiency standards, skylighting was added as prescriptive requirement for low rise buildings with enclosed spaces directly under a roof greater than 25,000 sf and having a ceiling height greater than 15 feet. These spaces were selected because skylights are most cost-effective in area with high ceiling heights because the skylights can be spaced further apart while yielding sufficient illuminance uniformity. Also skylighting systems in buildings with suspended ceilings have the added cost and light losses associated with light wells between the skylight and the suspended ceiling. The current skylight market tends to be in spaces with high ceiling heights and large open spaces for the economic reasons described above. Thus, this relatively bold requirement would be initially required in those buildings where it is most cost-effective and there is a substantial prior experience with apply skylighting. The thought is that once this measure has been established in these large open building types that even more designers and contractors would become increasingly experienced in skylighting design and construction. As a result, that it would be increasingly feasible to expand the requirement to smaller spaces while yielding reliable and cost-effective savings.

b. Code question – Should the skylighting requirements be extended to smaller buildings?

The rationale of this code change would be to encourage skylighting and photocontrols in small retail, warehouse, library, office and possibly other commercial buildings in the state. The primary question is what is the smallest feasible space size for a stand-alone sky lighting system? Feasibility includes issues of likely occupancy and ownership of the space. With smaller spaces are the users sophisticated enough to realize the benefits of maintaining their photocontrol system?

Potential research approaches –

- Survey other successfully daylit space types with different spaces sizes to identify additional spaces suitable for daylighting controls requirements
- Identify and evaluate barriers to using toplighting in smaller spaces.
- Generate cost and savings estimates for daylighting controls in the additional space types to establish cost effectiveness
- Develop industry consensus on best practice and acceptance testing protocols for photocontrols in smaller skylit spaces, based on real-world experience with successful control systems

c. Code question – Should the skylighting requirements be extended to buildings with lower ceilings?

When skylights are applied to spaces with lower ceilings, both the increased first cost of creating the light well and the decreased amount of daylight available due to losses in the light well have to be considered. Also, this change would increase the occupancies from primarily big box retail and warehouse to a much broader range of occupancies including schools, offices, medical etc with more demanding occupant requirements. It is likely this is a more demanding requirement than reducing the minimum size where skylighting is required.

Potential research approaches –

- Survey other successfully daylit space types with lower ceilings to identify additional spaces suitable for daylighting controls requirements
- Identify and evaluate barriers to using toplighting in spaces with lower ceiling heights.
- Generate cost and savings estimates for daylighting controls in the additional space types to establish cost effectiveness
- Develop industry consensus on best practice and acceptance testing protocols for photocontrols in skylit spaces, based on real-world experience with successful control systems

d. Code question – Should louver controls be added to skylights to gain additional energy savings?

Currently the term "daylighting controls" is often considered synonymous with photocontrols to reduce electric lighting when sufficient internal daylight is available. However, daylighting controls encompasses a larger realm of controls that controls the admission of daylight into the interior in response to exterior daylight availability to meet the visibility requirements and in addition reduces electric lighting in response to resulting interior daylight.

Since the magnitude of daylight varies of the course of the day, by month and by sky condition, at any given hour the available daylight in a skylit space is likely above or below the design illuminance. By adding louvers, the visible light transmittance and solar heat gain of the skylighting system is reduced. The louvers can be modulated to further reduce light transmittance and solar heat gain so that a daylighting system does not over light and overheat a space. In addition, the louvers can be closed at night and thus reducing heat losses and reducing light pollution to the night sky.

The questions this concept raises are:

- What is the linkage between reductions in visible light transmittance and solar heat gain coefficient? What is the reduction in night time thermal losses? What is the net energy and demand impact of louvers?
- How much cost do louvers add to a building and are they cost effective?
- Do louvers and their controls work reliably and save additional energy over the long term?
- How are louvers received by designers and the building occupants? What are the non-energy impacts?

Potential research approaches –

- Laboratory experiments to characterize the thermal and luminous properties of louvers. This might include calorimetric measurements for solar heat gain and guarded hot box measurements for U-factors.
- Interviews with designers who have added lovers to skylighting systems to discuss design issues and integration challenges and costing.
- Site surveys of buildings with louvers to monitor performance and interview occupants on their reaction to louvers.
- Research on design issues that impact louver longevity.

4.2.2.3 Sidelighting requirements

Daylighting controls have been in use in a few sidelit buildings (predominantly offices and classrooms) around the state, and there are a number of manufacturers who are developing newer models of photocontrols for sidelit buildings. These controls are purported to save significant amounts of lighting energy in daylit spaces. However, some anecdotes would indicate that the maintained savings is actually low due to these systems being disabled or malfunctioning. Since approximately 36% of commercial floor space is within 15’ of the building perimeter (the traditional definition of the daylit area is within 15’ of a window) the energy savings opportunity is quite high if we can be assured the savings from daylighting controls are real and can be maintained over time.

A study soon to be commissioned by the California utilities plans to collect data on the effectiveness of daylighting and photocontrols in sidelit buildings through field surveys and monitoring. Data from this study would provide the ability to work on future standards provisions for photocontrols in sidelit buildings.

a. Code question – Should the daylighting controls requirements be extended to sidelit buildings?

The answer to this question lies partly in the findings from a survey of existing installations to identify successful applications of photocontrols in sidelit buildings. This survey is being commissioned by SCE, PG&E and NEEA, and will be completed by early 2005. In order to develop a daylighting and controls requirement, there needs to be a clear understanding and definition of the daylit zone in sidelit buildings. There also needs to be consensus on appropriate controls, as well as nature of control.

Potential research approaches –

- Analyze data from the soon to be commissioned statewide survey of photocontrols to identify spaces most suitable for photocontrols
- Refine the daylit zone definition in Title 24 based on best practices found from the field surveys.
- Develop an hourly method of calculating energy savings from photocontrols to enable Time Dependent Valuation (TDV) analysis of photocontrols performance

- Define best practices and acceptance testing requirements for photocontrol systems in sidelighting applications, including type of photosensor, photosensor placement, control logic, use of overrides, etc.

4.2.2.4 Lighting controls as a load shedding and demand savings approach

The Commission staff anticipates continued problems with electricity reliability in the state of California. Demand response is already a big issue, and demand responsive technologies are increasingly available. The Commission/PIER program has therefore taken the lead in the creation of the Demand Response Research Center, which will coordinate development of demand responsive technologies. Lighting controls figure to be an increasingly important demand response technology that will be promoted in the months to come. Some researchers and policy makers feel there is a need for the codes and standards to mandate the use of certain demand responsive lighting technologies.

a. Code question – How can Title 24 encourage greater use of load shedding lighting technologies?

Title 24 currently provides a voluntary Power Adjustment Factor (PAF) credit for the use of manual dimming with automatic load control of dimmable electronic ballasts. During the recent California summer demand crisis, voluntary load shedding from switching off of lighting was very effective and widespread. Most utility-level load shedding strategies have focused on large industrial users or on air conditioning, which frequently just shifts the load by a few hours. Shedding lighting load can be done quickly and the energy savings are absolute rather than shifted. There are operational and behavioral aspects of lighting load shedding, however, which are not well understood for the population of buildings and occupancy types.

Potential research approaches –

- Conduct controlled field trials of lighting load shedding strategies, while measuring achievable demand reduction levels and occupant response. Compare permanent load reduction to dispatchable load shedding strategies for both impact on occupants and electricity system benefit.
- Develop cost effectiveness criterion for load-curtailment that meets utility and CPUC demand control goals

b. Code question – How can daylighting and building design help load shedding and demand control in commercial buildings?

Lighting control systems can be used to provide short-term load shedding capability, as in response to a day-ahead price signal or an emergency request. An alternative strategy is to use lighting controls for permanent load reduction, which would generate greater energy and demand savings, and longer-term economic incentives for building owners. Both strategies are achievable when lighting reductions are accomplished in combination with good building design and daylighting. Energy savings over the course of a year from daylighting are relatively well understood, but demand reduction is less understood. The timing and coincidence of daylighting and system peak are important and need further study.

Potential research approaches –

- Model the lighting schedules for various buildings types and analyze the impact of daylighting control operation on those schedules, both for energy and for demand.
- Estimate the statewide emergency load shedding potential if the maximum amount of lighting were turned off in daylit spaces.
- Assess costs and benefits of daylighting controls systems that combine both emergency load shedding capability with routine lighting power reductions in the presence of daylighting

4.2.2.5 Dimmable Electronic Ballasts

A number of proposed energy efficiency measures, such as daylighting controls, load shedding or multi-scene controls as well as simple lighting reduction from manual dimming, are dependent on the availability and cost effectiveness of dimmable electronic ballasts for fluorescent lighting. The 2005 Title 24 standards encourage the use of dimmable electronic ballasts through a voluntary power adjustment factor for the use of electronic dimming ballasts in conjunction with load shedding. A study conducted for the PIER LRP program, however, demonstrated that dimmable electronic ballasts are 2-3 times as expensive as regular electronic ballasts. Technology differences alone do not account for the price difference.

a. Code question – Should dimmable electronic ballasts be promoted further through standards? How?

Currently, dimming ballasts are infrequently used as their cost is high. But there are other performance issues that also create barriers to greater use of dimming blasts and some of these are related to standardization. Certain dimming ballasts may operate better with a particular manufacturer of lamps than others because each of the lamp manufacturers makes the lamp cathodes differently, and the relationship between optimal cathode temperature and lamp current are different for different lamps.

In designing a control circuit for dimming ballasts, it is hard to generate an appropriate control voltage that is appropriate for all ballasts as some ballasts start dimming at 9 Volts and others at 7.5 volts. An industry standard of ballast light output in response to control voltage would be a benefit for the lighting controls industry and the users of dimming ballasts and lighting controls.

Potential research approaches –

- Identify spaces and applications where dimmable electronic ballasts would save the most energy costs and have the highest non-energy benefits for their users.
- Identify barriers to electronic ballast cost effectiveness, and identify trends in available products that lead to reduced costs.

- Identify important non-energy attributes of dimming ballasts (lamp/ballast compatibility, lamp or ballast longevity, flicker, standardization of controls signals).

4.2.2.6 Programmable Lighting controls

Lighting controls for commercial applications are rapidly evolving, with more flexible controls offering 'scene' controls becoming cost effective for high-end applications. Currently, these controls are not cost-effective for mass consumption; however they are used by a portion of the market, and may replace traditional lighting control functions such as bi-level control and interface with occupancy sensing. It is critical to understand how such programmable controls might affect commercial lighting energy consumption and the related effectiveness of Title 24's lighting control requirements.

a. Code question – What are the capabilities of programmable lighting controls available currently for the commercial market?

While programmable controls may offer higher savings in some applications, by improving on the energy-saving control strategies required by Title 24, it may also be possible that the controls be easily reprogrammed as to defeat these code provisions for controls and switching.

Potential research approaches –

- Identify the energy efficiency capabilities of existing programmable lighting controls for commercial applications
- Quantify the energy and demand savings potential of programmable controls
- Identify impacts on Title 24 code compliance due to programmable controls
- Work with manufacturer product development and advisory groups to develop specifications that can ensure products satisfy Title 24 control requirements and deliver expected energy savings, while accommodating the desirable flexibility features of programmable controls

4.2.3 Lighting Power Densities for Commercial Buildings

4.2.3.1 Compare ASHRAE 90.1 LPD allowances to 2005 Title 24 LPD allowances

ASHRAE recently updated the 90.1-2001 standards through the issuance of an addendum. This addendum includes updates to the lighting power densities in the space-by-space method and building area method. These updates were done in order to make the ASHRAE standards comply with the recommendations in the 9th edition of the IESNA handbook. Part of the reason for changes in the LPD values was the change in the lighting technology efficiencies and light loss factors. The lamp efficacy for each of the 35 generic luminaire/fixture types and the associated lamp lumen depreciation factors were reevaluated based upon current, commonly available technologies. A recent study (Luminaire Dirt Depreciation Study, July 2000, NALMCO No. CX824574-01-0) was used to update these values for most fluorescent luminaire types. The luminaire dirt depreciation value for all remaining types was reviewed against the latest IESNA Lighting Handbook.

The Commission is investigating if the new ASHRAE LPD allowances are lower than the 2005 CA Title 24 LPD allowances. If this is the case, the Commission would be interested in investigating the reasons for the lower LPD specifications, with the aim of possibly modifying the T24 LPD values.

a. Code question – What are the differences between ASHRAE 90.1, the 2005 Title 24 LPD allowances, and actual practice?

Potential research approaches –

- Develop area category and whole building LPD models using both ASHRAE and Title 24 allowances to compare differences
- Collaborate with IESNA and ASHRAE to determine the most energy efficient allowances for future round of Title 24 standard LPDs
- Compare the ASHRAE and Title 24 LPD values with the ranges of installed LPDs observed in various commercial building types, utilizing existing databases such as the Nonresidential New Construction (NRNC) database for installed LPDs. Document stringency of the LPD standards versus actual practice.

4.2.3.2 Revisit tailored method of compliance

The purpose of the tailored lighting method of compliance is to provide flexibility for applications that have unusual lighting requirements, and for which it is felt that the standard lighting power densities are too stringent. On one hand it is seen as the “pressure relief valve,” to mute opposition to the relative stringent lighting power densities in the whole building method or area category method of calculating allowable lighting power. On the other hand, the tailored lighting method is complex enough and relies on the lighting designers “judgment” so that it is essentially a carte blanche to install high wattage lighting systems. Thus the concern is that the method is a loophole primarily used by retailers to increase the lighting in their store without really rethinking how much light they need. This in turn leads to “light wars” between retailers as people have a phototropic tendency and are attracted to light.

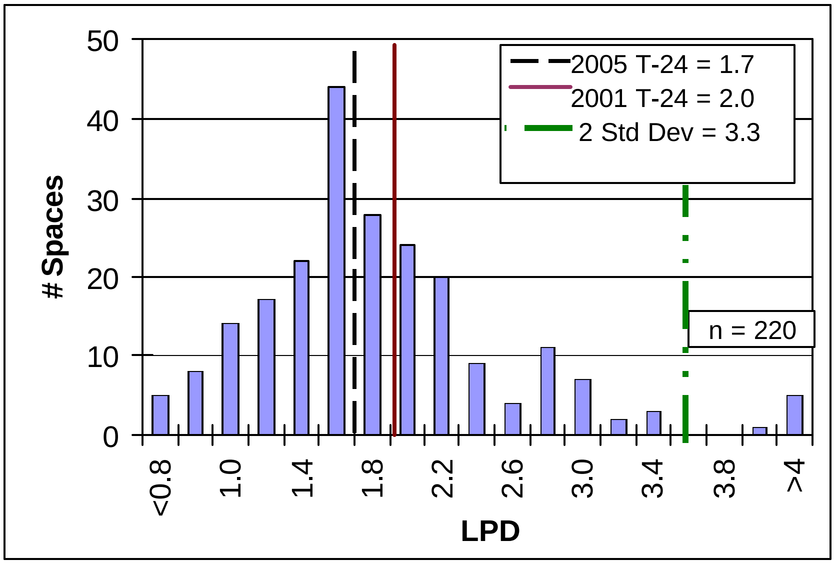


Figure 7: Distribution of retail and grocery lighting LPD's from NRNC database

Unlike most space types where the LPD requirements are eliminating the top few percentile of lighting LPD's used in the state, the new 2005 standards would disallow around 50% of the current lighting designs that were installed over the last 5 years (see Figure 7). Unlike other space types, retail has a significantly greater standard deviation of LPD's. It implies the retail lighting space types could be in need of further segmentations for the purposes of setting appropriate lighting LPDs in the Title 24 standards.

Some people believe that the need for the high lighting power densities is merely because lighting designers like the relatively inefficient but highly directional halogen and incandescent sources over the more efficient but diffuse fluorescent sources. If this were the entire story, then perhaps advances in small wattage ceramic metal halide sources would perhaps be a technological fix to the tailored lighting problem and the LPD's could be adjusted to account for ceramic metal halide spot lighting of retail.

However, in review of the nonresidential new construction database of 154 retail buildings, the data did not bear out the hypothesis that inefficient incandescent and halogen lighting was responsible for high total lighting power densities of stores. Instead, as shown in Figure 8, these inefficient sources were a relatively small fraction of the total LPD. This indicates that when a store has a light lighting power density, it also has high light levels.

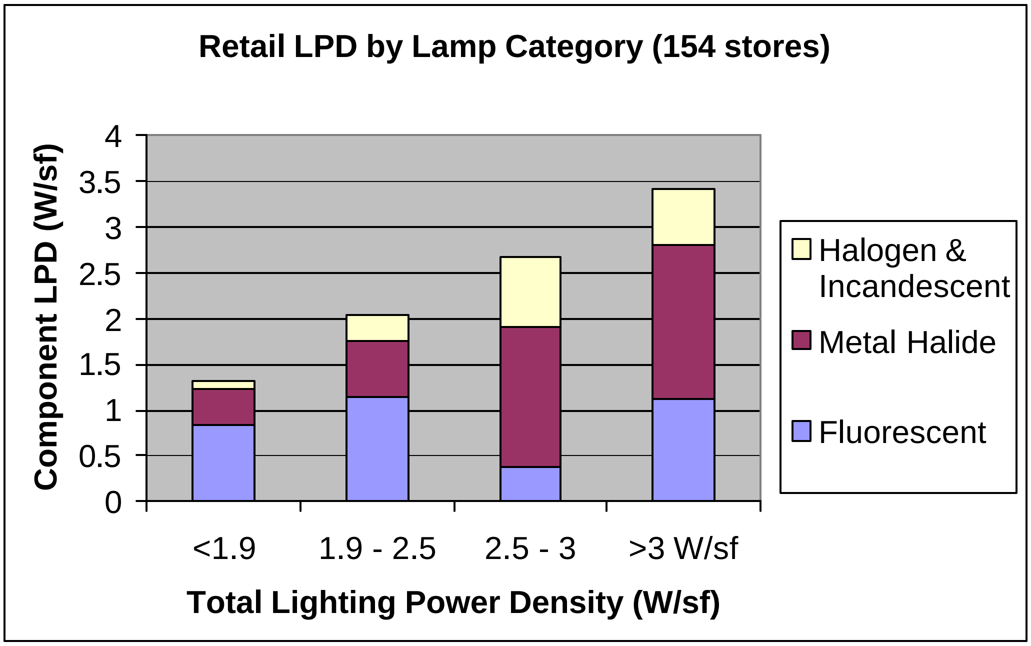


Figure 8: Components of lighting LPD's (lighting power densities) with respect to overall LPD's

This indicates that the motivation for using the tailored lighting method cannot be characterized as driven by the desire to use inefficient point light sources. When higher LPD's are installed they still are predominately in the form of fluorescent and metal halide lighting. Increasing the efficiency of directional lighting sources would have only limited impact on the efficiency of retail lighting.

This would indicate that if the efficiency of retail lighting is going to be addressed, then the focus of research is on as much or more on retail lighting design methods and lighting criteria than on source efficacy.

a. Code question – What are the visibility requirements of retail lighting aside from historical design techniques and competition with historical light levels?

Potential research approaches –

- Survey the lighting design community to determine how often they use the tailored method, and for which applications
- Perform lighting surveys on spaces that require tailored lighting to comply to identify installed LPDs, component breakdown by lamp and fixture types and task needs in those applications
- On a task type-by-type basis work with a team of retail lighting designers to develop a new set of lighting design patterns. Identify what differentiates these tasks and use this to segment retail lighting in to subclasses.
- From these subclasses of retail lighting and high efficiency lighting patterns develop a new set of comprehensive lighting efficiency requirements for the various subclasses of retail lighting.

4.2.4 Stairwell Lighting Standards

Stairwell lighting typically does not garner much attention in the codes and standards development process. Stairwells are governed by the building and fire codes than the energy codes due to their safety and path of egress concerns.

However, due to the recent horrific attacks on the World Trade Center in New York and a disastrous fire in a nightclub in Rhode Island, public attention has again been focused on the importance of stairwells that are typically out of sight and out of mind.

There are three key factors to the safe use of stairs: visibility, geometry of steps, and handrails. However, only visibility has an ongoing cost impact because building and fire codes demand that paths of egress for most commercial and large, multi-story residential buildings must be lighted 24 hours every day—whether used or not.

To date, energy costs for lighting have been modest because codes have required that exit stairs be lighted to only one foot-candle (1fc or 10.8 lux). Code bodies have been reassessing this requirement and several have already accepted proposals that require lighting for exit stairs be increased to 10fc (108 lux) during occupancy. To mitigate the large jump in energy costs that would accompany such a requirement, these codes are also allowing the use of new lighting control technology that will reduce stairwell light levels back to 1fc (10.8 lux) during unoccupied periods.

The American National Standards Institute (ANSI) accepted the 10fc illumination requirement on November 26, 2003 through the American National Standard 117.1-2003 Accessible and Usable Buildings and Facilities. The requirement also allows the use of lighting controls to set the light levels back to 1fc when there is no occupancy in the space.

Similar standards have since been accepted by the National Fire Protection Association (NFPA). The NFPA 1: Uniform Fire Code™, 2003 Edition also requires that the lighting controls fail in the ON position, that is, if the sensor fails, the lamps will be at full light output. Same requirements have been adopted into NFPA 101 – Life Safety Code, and will be adopted into the next round of NFPA 5000 – Building Construction and Safety Code. The NFPA 5000 code is in direct competition with the ICC (International Code Council) codes. There has been a movement afoot by the California Building Standards Commission to adopt the NFPA 5000 standard.

The focus on lighting levels is perplexing because two issues that came out of survivor reports was that some areas of the building were plunged into darkness – indicating that emergency lighting circuits did not work and that exit doors were chained shut – against the requirements of existing building codes. Increased light levels in stairways require more lighting power which could perhaps be more likely to discharge batteries prematurely and create a more serious problem of no light at all.

It is understandable that building codes should react to measures that can reduce the number of injuries from a terrorist attack or other emergency. However, these measures need to be based upon objective technical data.

Given all this background on developing national codes on illumination and controls requirements for lighting in stairwells due to safety concerns in the post-9/11 world, the question of energy impacts of such decisions need to be studied in the California context.

a. Code question – what is the illumination level and uniformity needed in stairways to quickly and safely evacuate a building? Is this illumination level based on other aspects of the stairway geometry, reflectance etc?

This study would answer the key questions of what is needed to have safe and effective stairwell egress system

Possible research approaches

- Laboratory study of occupant ability and duration required to leave a building when stairwells are under different luminous conditions.
- Study would be conducted with an without smoke and with and without noise from sirens
- Study would be conducted under different conditions of reflectances of stairwell walls and stair reflectances, markings etc.

b. Code question – what are the energy impacts of the ANSI/NFPA decision to require 10fc illumination in stairwells when occupied, for the State of California?

Currently, precious little data is available for the amount of energy consumption in stairwells in terms of installed lighting power densities, schedules, and controls. The PIER LRP program collected data on four case study buildings to analyze energy impacts and savings possibilities by installing a bi-level enabled stairwell lighting fixture that follows the NFPA and ANSI requirements mentioned above. Initial data indicates that there could be significant savings in low-use stairwells over the existing lighting fixtures. However, it is not known how representative these four case study buildings are of the overall stairwell population in the state.

If the savings are real, and there are significant energy savings possible, there could possibly be a control credit for bi-level stairwell lighting in the next round of standards.

Possible research approaches

- Conduct statewide survey of existing stairwell lighting installations for
  - Lighting power densities
  - Illumination levels
  - Occupancy schedules
  - Type of stairwells
  - Type of buildings
- Analyze energy impacts of the new 10fc illumination standards on the existing stairwells based upon data collected via the survey described above

4.2.5 Light Emitting Diode Fixtures

A number of industry groups, research institutes, and other agencies are actively promoting the development of more efficient and efficacious LED fixtures. Currently, LEDs do not meet the high-efficacy source requirements of the Title 24 standards, and may not meet those requirements for the next few years. Some in the industry have claimed that the current performance metric (lumens/watt) is unfair when it comes to LEDs. The luminous flux metric does not differentiate in terms of distribution of light but rather sums up the luminous flux emitted by a source and divides by the input Watts, LEDs are highly directional and it is argued that LEDs can be more efficient when you take their directionality into account.

LEDs have a very narrow beam spread, and can deliver more lumens/watt in that narrow area than other diffused sources like CFLs. Also, it is possible to make very low wattage (and low light output) LED products that might replace higher efficiency, but significantly higher light output products so that the LED uses less power. In some cases, the monochromatic nature of LED light is also a benefit. When colored light is desired, the LED's system efficiency can be higher than light from an efficient white source that is then filtered. Indeed, LEDs may offer efficiency advantages over other sources in certain applications. These three effects are what when combined render LEDs valuable for exit signs. Exit signs with less than 5 Watt per face of maximum lamp input power (such as LED exit signs) are exempt from the calculation of lighting power in the 2005 version of Title 24 (§146(a)5).

a. Code question – Do LEDs merit consideration for acceptance by the Title 24 standards?

The PIER program is currently funding three studies on the use of LEDs in residential and commercial lighting. There is an argument that there should be a special consideration for LEDs for specific applications such as low-level standby lights for wayfinding, pathway, landscape, porch lighting etc. Equally compelling is that LEDs should be regulated in terms of efficacy it they are being combined to replace a light source that does not need a highly directional, small wattage or colored light source.

Potential research approaches –

a. Develop technical criteria for improved LED performance metrics such as maintained lumens, lumens/watt, and demonstrate validity through testing of both LED and non-LED luminaires.
b. Develop design guidelines for energy effective use of LEDs as standby low level lighting for wayfinding and indicator lights, based on technical evaluation of source and luminaire efficiencies.
c. Develop efficacy requirements for colored signs based upon the lumens of light transmitted by the color filter divided by the input watts. This would advantage colored sources such as discharge lamps and LEDs as compared to the current source efficacy metric.

4.2.6 Acceptance Testing Requirements

The 2005 Title 24 standards include acceptance testing requirements for various controls including lighting controls such as occupancy sensors and photosensors. The aim of these requirements is to ensure that all sensors installed in Title 24 compliant buildings meet minimum standard operational specifications, and provide reliable and repeatable savings. Pilot studies are currently being conducted to verify the accuracy and applicability of these acceptance testing requirements for HVAC and lighting controls.

a. Code question – How effective are the acceptance testing requirements for lighting controls?

Potential research approaches –

- Interview lighting designers, specifiers and contractors on enforceability of the acceptance testing requirements after the requirements have gone into effect
- Observe the conduct of acceptance tests, interview the contractors on the pluses and minus of the tests, monitor the performance of lighting controls that have acceptance tests versus those that do not and suggest improvements to the acceptance testing requirements

4.3 OUTDOOR LIGHTING

4.3.1 Update (or refine) Outdoor Lighting Regulations

The 2005 standards include sweeping new provisions for outdoor lighting, including definitions of applications, LPD limits for many applications, efficiency requirements for some lighting sources, control requirements for some sources, and definition of California Lighting Zones that determine applicable standards. It is unknown how these standards will be received and implemented by designers, building owners, and code enforcement officials. Furthermore, given some of the uncertainties and controversies surrounding the development of the 2005 standards it would be prudent to answer some of these questions before considering any changes in the 2008 code cycle.

a. Code question – Is the current baseline for outdoor lighting installed LPDs adequate for future legislation?

In 2000 the Commission undertook the first ever survey of commercial outdoor lighting energy use via one of the PIER programs. This project was hailed by members of the IESNA as a great step forward in understanding current outdoor lighting practices, and described as a “massive” database. In reality, the project had very high ambitions but a limited budget. As a result, both the data collection and analysis were left incomplete in many ways. Trying to capture a representative sample, the budget allowed for a very limited number of on-site surveys to represent all commercial outdoor lighting use across the state. As a result, a number of important applications types, such as gas stations and vehicle sales lots were inadvertently underrepresented in the sampling, making portions of the analysis thin and unreliable. Budget constraints also dictated that much of the originally collected data on lighting quality and user preferences remained un-analyzed and un-reported. This data could be analyzed to understand how existing outdoor lighting power densities correlate to perceptions of lighting quality and utility.

A credible initial outdoor lighting baseline, with periodic updates, is necessary to allow the Commission to define current practice, and track changes over time. Understanding change over time is essential. The Commission should be concerned with both understanding if the new code is actually working to reduce energy impacts, and whether other trends in the industry, such as new technologies or practices, may have substantial positive or negative impacts.

Research approaches

- Complete the initial Outdoor Lighting Baseline, with sufficient resolution for each application type by California Lighting Zone.
- Analyze the Outdoor Lighting Baseline for correlation of existing lighting power densities to perceptions of lighting quality.

b. Code question - Are we allowing more lighting energy usage than standard practice as result of the 2005 Title 24 outdoor lighting requirements?

One concern with the new 2005 outdoor lighting provisions is that they may actually work to increase the use of lighting energy in the State.

The 2005 standards were largely based on calculations derived from design practice recommendations published by the IESNA. When there was more than one recommendation to choose from, the Commission used the most liberal (in terms of energy use) as the basis.

However, if these recommendations substantially exceed actual current practice in the State, then the 2005 standards could set a more energy intensive design criteria than was previously applied. This could happen by creating the presumption of the energy code defining a “legal standard” for outdoor lighting, where before there was none. Thus, it is possible that building owners who previously would have provided minimal, or even none, nighttime lighting will now feel that they should provide lighting levels similar to those used as a basis for the code.

Research approaches

- Compare LPDs generated from outdoor lighting models based on IESNA standards to findings of the Outdoor Lighting Baseline.
- Survey building owners on attitudes to outdoor lighting preferences relative to information about the Title 24 2005 provisions.

c. Code question - What is an acceptable baseline for outdoor lighting energy usage?

A related controversy centers on how the energy standards should be developed and justified. Should the baseline for energy use of outdoor lighting systems be determined by professional design standards or by observed actual practice? The first approach suggests that standards should be developed from carefully crafted models applying the best professional standards. The alternative suggests that by simply identifying and prohibiting the least energy-efficient 10% or 20% of current practice, energy efficiency will be improved without overly constraining current practice. It is not necessarily obvious which approach will result in better acceptance or better energy efficiency.

Outdoor lighting practice varies dramatically from the ad hoc to high art. While indoor lighting practices have been extensively studied and standardized over the past one hundred years of experience on the basis of human visual needs, outdoor lighting has had substantially less attention and resources devoted to its development. With ever increasing use of automobiles in the past century, the greatest area of research and development has been for roadway lighting. Other areas of outdoor lighting, such as retail signage, façade lighting and landscape lighting have been driven more by aesthetics and/or competition for attention than by research into basic human visual needs. As a result, the range of practices varies widely, as do the recommendations of various committees of the IESNA. Indeed, committee recommendations occasionally vary even to the point of conflicting with each other.

The default assumption of the professional societies has often been that darkness at night is a hindrance to human visual performance, and that higher levels of electric illumination are therefore universally desirable. However, the reality is that humans can function well at night with many other visual strategies besides simply raising the level of electric illuminance. Only in 2002 did the IESNA adopt a requirement that all relevant committees consider “when NOT to light” in their outdoor lighting recommendations.

Research approaches –

- Complete the initial Outdoor Lighting Baseline, with sufficient resolution for each application type by California Lighting Zone.
- Correlate light levels detected by satellite imagery to the California light zones.
- Compare LPDs generated from outdoor lighting models based on IESNA standards to findings of the Outdoor Lighting Baseline.
- Survey building owners on attitudes to outdoor lighting preferences relative to information about the Title 24 2005 provisions.

d. Code question - Will the provisions for bi-level controls in outdoor lighting applications have positive energy and economic impacts?

The 2005 standards required that certain outdoor lighting applications include a capability to operate at partial power. This provision was intended to provide capability for load shedding and/or curfew lighting reductions should they be desired by a future building owner, or required by a state or local government agency. It is unknown how these provisions will be implemented or their actual cost impacts.

Research approaches –

- Include information about the implementation of bi-level capability in future (trend-line) Outdoor Lighting Baseline data collection, including design strategies and costs.

e. Code question – Are the California Lighting Zones sufficiently well defined, communicated, and implemented?

The four California Lighting Zones were created following the lead of IESNA and CIE in suggesting the use of four "environmental zones" for outdoor lighting. However, the California Lighting Zones were specifically defined on the basis of US Census data and boundaries since the US Census data was legally reference-able and periodically updated. The presumption is that there is a correlation between habitation density as defined by the Census and outdoor lighting energy needs. This presumption has been challenged by others outside of the State who believe that habitation density is a poor proxy for lighting energy needs.

It is unknown how local jurisdictions will react to the new 2005 provision for regulation of outdoor lighting by Lighting Zone. Local jurisdictions have the authority to change the default Zones in their area, and may choose to significantly alter the default conditions.

Research approaches –

- Correlate data from the Outdoor Lighting Baseline (and subsequent studies) to the California Lighting Zones to understand the degree in variation in illumination levels by application type by Lighting Zone.
- Survey local jurisdictions to understand their awareness of and reaction to the Lighting Zones.
- Collect case study information about how local jurisdictions are modifying the lighting zones, why, and via what processes.

4.3.2 Outdoor Signage Lighting

The 2005 standards attempted a first-ever regulation of energy use by outdoor illuminated signs. The initially proposed provisions were controversial and eventually revised to simpler and less aggressive levels in order to accommodate objections, primarily by members of the outdoor sign industry.

a. Code question – Is the regulation of illuminated signs feasible and enforceable?

Some members of the sign industry made a strong assertion that the energy use of outdoor illuminated signage should not be regulated, as any such regulation would interfere with options for free speech. At the time the Commission made the determination that it did have the mandate to regulate the energy use of outdoor illuminated signs, based on the enabling legislation. However, the boundaries between choices in energy use and options for free speech may continue to be an issue that should be further resolved.

Another issue arose as to whether energy use by signs should appropriately vary by California Lighting Zone. In the absence of clear standards for visibility and the impact of glare sources on nighttime vision, it was difficult to make the case why a sign in a high density area (Lighting Zone 3 or 4) might require an allowance for more energy use than one in a low density or intrinsically dark area (Lighting Zones 1 or 2). As a result, the energy use standards for signage did not vary by Lighting Zone as they did for other outdoor lighting applications.

b. Code question – Can we establish a more uniform, technology neutral method for appropriately regulating the energy use of illuminated signs?

There is not only a wide range of light sources used for illuminated signs, but there is also a wide range of design strategies for how to increase the visibility of signs at night. The 2005 standards did not develop a uniform approach to regulating all illuminated signs, but rather defined different metrics for different approaches and technologies, and exempted some systems entirely.

The key purpose of an illuminated sign is to be visible at night. Visibility is a function of many factors, such as size, color, luminance, contrast, adaptation level of the viewer, speed of the viewer, and surrounding conditions. However standards for visibility of signs are not clearly defined by professional societies; neither are types of signs, purposes of signs, or the size of signs. Without clear performance standards or definitions it is difficult to develop appropriate energy regulations. As a simple example, it is difficult to use a Watts per square foot metric, as is commonly used in other parts of the energy code, when it is unclear how to define the useful square footage of a sign.

Ideally, an energy code would use a metric of energy use per unit of performance. Such a metric would be technology neutral. It would seem that the unit of performance for signs should be related to visibility, such as luminance for the intended viewer. Luminance in areas other than the intended viewing area would be wasted. This implies that a viewing angle-dependant system might be developed, that could potentially also address undesirable glare and light trespass.

Ideally, a metric for energy regulation is also easily understood and controlled during the design and specification process and can be easily verified during inspection. Thus, such a metric should be tied to the product design and clearly understood by manufacturers, designers and installers. This implies that any such metric be rooted in industry practices and be widely accepted and easily identified.

Basing energy regulations on a metric that meets all of the above criteria would greatly increase the effectiveness of illuminated signage regulations. If such a metric can be designated and accepted, it may help drive further innovation in the sign industry.

Research approaches –

- Identify existing industry standards, metrics and terminology for all types of illuminated signs.

- Collect and analyze data on current sign energy use and how it correlates to visibility and other metrics of visual performance.
- Work with manufacturers, designers and researchers to identify the most energy efficient design practices.
- Work with manufacturers, designers and researchers to define a universal metric of energy efficient performance for illuminated signs.

c. Code question – Can we define an appropriate metric for regulating the energy use of LED signs?

Illuminated signs using LEDs are a recent phenomenon, and quickly evolving. They include LEDs used as a light source inside of filtered channel letters, LEDs used directly for an image, and animated signs, where each LED serves the function of a pixel on a VDT screen. Given the rapid development of the technology, the variety of application conditions, and a number of applications that promised high levels of efficiency, LED signs were excluded from efficiency thresholds in the 2005 standards.

LED signs face similar regulation challenges to all illuminated signs, as discussed above. However, they also have some fairly unique issues that create additional challenges for regulation. Most LEDs currently in use are colored light sources which are not appropriately measured by simple lumen output. Lumens are a measure of white light normalized to the daytime sensitivity of the human eye. While color specific lumens can be defined, they are not easily comparable across colors.

The energy use of LEDs is highly influenced by application design, such as heat dispersal. Thus, LEDs should not be rated for source efficiency, but rather application efficiency. Similarly, when colored LEDs are matched with similar colored filters, they achieve much higher visual efficiency than when paired with dissimilar colored filters. Thus again, the efficiency of the system is more important then that of the source. In a further example, animated signs utilize only a portion of the LEDs for any image at any given time. Thus, dynamic use patterns are more important in determining energy use than installed wattage.

Many LED signs, especially large animated LED signs, are used for daytime displays. The brightness required for legibility during daytime conditions is considerably brighter than that required at night. As a result, an LED sign designed for daytime conditions can be excessively bright at night. Another current feature of many LED signs is rapid lumen depreciation from initial output. In compensation, many installations have been designed to be excessively bright initially, in anticipation of lower brightness in the future. LEDs do have the capability for simple line voltage dimming and thus potentially could be adjusted for brightness based on varying needs.

All of these characteristics pose a challenge for energy regulation. On the other hand, LEDs are a rapidly developing technology that is likely to have an ever increasing range of applications and use. Thus, defining an appropriate energy performance metric for LED signs may have potentially large future impacts.

Research approaches –

- Work with manufacturers, designers and researchers to identify appropriate metrics of performance and energy use.
- Using those metrics, identify the most efficient design practices.
- Identify how dimming controls can be used to control energy use and visibility.

4.3.3 Nighttime Adaptation and Visibility

In order to set appropriate standards for outdoor lighting, it is necessary to balance an understanding of both the human need for and any negative impacts of outdoor lighting.

a. Code question – Can a scientific method of determining illumination needs for outdoor lighting be developed? Can such a method be employed by professional societies (and the code) to refine current outdoor illumination standards?

The Commission's interest in controlling energy use for nighttime lighting converges with other interests in reducing potential negative public health impacts, ecological impacts, scientific (astronomical) and other cultural impacts of excessive outdoor lighting.

The question at hand, for this report, is what level of participation in supporting such research and development of outdoor lighting tools and standards would be appropriate for the Commission? This clearly needs to be a national effort. However, to date, the topic has suffered from lack of clearly defined goals, lack of an urgent timetable, and a need for multi-disciplinary work which ranges outside the narrowly defined mission of most funding agencies. Funding from other sources would be more likely if there was a demonstration of measurable impacts in their specific areas of concern. For example, nighttime lighting impacts on endangered nocturnal species would involve environmental protection agencies; reduction in elderly populations' nighttime mobility and social participation would engage social services and public health agencies.

Thus, in order to develop a broader political consensus on appropriate outdoor lighting standards, it would be useful to have more consistency in professional recommendations. These would ideally be based on a capability to predict human visual performance under real outdoor conditions, balanced with useful information about any negative social or environmental impacts of outdoor lighting.

Research approach –

- Review literature on visual acuity, conspicuity, glare, adaptation, and predictive models at low light levels and identify gaps in current understanding.
- Convene a group of interested experts to prioritize a research agenda for outdoor nighttime lighting research and goals for development of a predictive tool.
- Quantify the various impacts of outdoor lighting, both negative, such as energy use, public health, ecological, and cultural impacts, and positive, such as safety, security, and commercial benefits.

- Define specific outdoor lighting tasks by application type, which can be related to specific visual acuity and conspicuity needs.
- Work with professional societies to develop a consistent and defensible methodology for setting outdoor lighting recommendations.

4.4 EXISTING BUILDINGS

Currently, the Title 24 requirements for lighting LPDs and controls apply to retrofits in existing buildings when more than half of the lighting fixtures are replaced during the retrofit. However, these requirements are fairly hard to enforce especially in residential buildings. For commercial buildings, tenant improvements may trigger a code compliance requirement if the envelope is being altered, or large scale lighting retrofits are being conducted.

Title 20 appliance efficiency standards also govern some aspects of the lighting retrofit market by regulating the energy efficiency of various components such as ballasts, lamps manufactured and sold in the state of California. There are constraints on the Title 20 regulations due to federal preemption that stipulates same efficiency levels for all the states, and disallows a state to have higher standards than the federal standard. This constraint is only valid for 4 foot (including 2 foot U-tubes) and 8 foot long fluorescent lamps and their ballasts. The remainder of lamps could be regulated by the state of California.

One area where the Title 20 standards could be improved in the specification of lamp/ballast combination efficiency of pin-based CFLs sold in the state. This is especially true of multi-lamp ballasts and multi-wattage ballasts.

a. Code question – Is there a need for efficiency regulation of CFL lamp/ballast combinations? Is there a need for better labeling of CFL lamps and ballasts?

Potential research approaches –

- Document range and variability of energy consumption between various lamp/ballast combinations through independent testing.
- Document range of longevity of CFL lamps and how a rating of longevity of lamps could be achieved.
- Identify need for consistent and clear labeling of CFL lamps and ballasts based on test data

4.5 MULTIFAMILY BUILDINGS

In the 2005 Title 24 code revision process some discussion revolved around the perceived need for a new code section dedicated to lighting in multifamily buildings. The basic context was that the proposed energy efficiency of lighting measures in a multifamily building should be based on schedules and lighting power densities consistent with an average multifamily building lighting energy consumption. Currently (and in the 2005 Title 24 standards) the residential code applies to multifamily buildings up to three stories tall while the nonresidential code applies to buildings of 4 stories or more—i.e., high rise residential. Furthermore, the common areas of multifamily buildings are treated like nonresidential while the dwelling spaces are treated as residential in most cases. The separation of one building type into different code bases is the source of considerable confusion and some unintentional energy efficiency loopholes. For example, corridors and other common areas in multifamily buildings can be considered residential if they are less than 10% of the total building area, while they are considered non-residential if they are above 10% of the total building area. Lighting efficiency requirements for the common spaces can therefore differ significantly from building to building.

A new code section dedicated to lighting in multifamily buildings would allow the standards to specifically address the lighting needs of this building type which by many estimates will be a rapidly increasing percentage of new residential construction in the coming years as land values increase and need for senior and low income housing increases.

a. Code question – Is there a need for separate lighting requirements for multifamily buildings?

Potential research approaches -

- Field research into the magnitude of energy consumption and energy savings possibilities in multifamily buildings
- Identify appropriate lighting power densities, schedules and controls for spaces in multifamily buildings

5. FUNDAMENTAL LIGHTING RESEARCH NEEDS

So far we have discussed the immediate and near-term needs for lighting research based upon the codes and standards development process. While this research is extremely valuable, it is an evolutionary research that builds upon existing knowledge of technologies (both established and developing), human response and societal needs. There are however research topics that require a more basic exploration of the fundamental principles underlining our current understanding of lighting. Scientists from diverse fields such as ophthalmology, biology, chemical engineering and electrical engineering are currently working on furthering our understanding of human vision, its response to light and the related technological issues. While these issues may be a long-term research, they will have profound effect on human productivity, health and technological development in the future. This will no doubt influence future codes and standards which will balance the needs for energy savings with human health, societal needs and technological barriers. Below is a brief summary of such research topics:

5.1 HUMAN EYE AND PERCEPTION OF LIGHT

Most of our lighting research is predicated on providing better illumination and visibility in the space while providing greater opportunities for energy savings. However, the field of human vision research is still in the development stage and there is much that we do not know about the mechanisms of vision and the impact of various light sources and light levels on the human eye.

5.1.1 Spectral Sensitivity of the Human Eye

a. Fundamental research question – What is the spectral sensitivity of the human eye? Can we develop a standard metric of evaluating human eye response to different spectrum of light at different levels of adaptation?

The spectral sensitivity of the eye at very low light levels and relatively high light levels has been established for some time. The spectral sensitivity of the eye is characterized by the photopic and scotopic efficiency curves. However there has been relatively recent research that indicates that under normal nighttime driving conditions, the eye is operating a mesoptic lighting regime somewhere in the middle between the photopic (daytime) viewing conditions and scotopic (dark) viewing conditions.

In the mesoptic regime there is some color perception. It may be that roadway and parking lot lighting consider neither a scotopic or photopic rating of light but rather one of this middle range of illuminance levels.

To the extent that a multi-spectral source allows one to differentiate between objects by their color, this increases acuity as compared to monochromatic light with the same photopic or scotopic lumens. Quantifying this color differentiation capacity of light may prove useful in outdoor lighting design. Once quantified, the value of color differentiation could be tested on its ability for avoiding roadway hazards.

b. Fundamental research question – Does the spectral content of CFLs and fluorescent fixtures disrupt circadian health?

Research from a number of quarters has found that light impacts the circadian rhythms (sleep and endocrine patterns) of many animals including humans. The hormone involved with circadian regulation is melatonin and several experiments have been able to identify that melatonin production in humans is impacted by the timing, the quantity and the spectrum of light exposure. This spectral sensitivity of melatonin production (or inhibition) is characterized by the melatonin action spectrum and the blue end of the spectrum has the most impact on melatonin production. Exposure to the blue wavelengths of light during the night is hypothesized to cause sleep disorders and other health effects.

If such an action spectrum is shown to indeed cause harm during night time exposure, this could impact the energy efficiency standards. Following the Hippocratic maxim of “first cause no harm,” light source requirements might also be evaluated in terms of their spectral content. Work performed at LRC indicates that there is a substantial difference in the theoretical melatonin impact between cool white CFLs, warm white CFLs and incandescent lighting.

Additional research would try to confirm whether night time exposure to certain sources of light do indeed impact circadian health. If the finding is positive then such a study could identify the prudent avoidance actions that simultaneously save energy and minimize melatonin disruption. This follow-on research would identify common sources of light at night and their magnitude and what solutions might be available. Is the source of light from certain indoor fixtures or from certain outdoor fixtures? In minimizing the impact of certain light sources is it most effective and feasible to change the light source or to improve shielding?

Findings from this type of research could ultimately end up in the lighting chapter of the residential Manual as well as in voluntary residential lighting efficiency programs.

Potential research approaches

- Laboratory or epidemiological (survey) study of the impact of different light sources and intensities on human melatonin production and health or behavior
- Survey of timing and intensity of light at night from different sources (outdoors, indoor lighting by fixture and location)
- Luminaire design to minimize circadian impact including source selection and spatial distribution of light
- Residence and residential neighborhood design guidelines to minimize circadian impact

5.1.2 Visibility Requirements for Security

An agreed fundamental basis of energy efficiency standards and programs is that efficiency measures must not reduce safety or security. However, little is known about the impact of various combinations of lighting properties on safety and security. In absence of information, decisions are made on subjective preferences "this feels safer."

a. Fundamental research question – What is the minimal illumination requirement for egress in emergency situations in enclosed stairwells?

In the interior of buildings, the issue of appropriate lighting for safety and egress has also been an area where opinions are divided. However, due to the recent horrific attacks on the World Trade Center in New York and a disastrous fire in a nightclub in Rhode Island, public attention has again been focused on the importance of stairwells that are typically out of sight and out of mind. A number of code-setting agencies such as ANSI, NFPA and others have either accepted revisions or are considering revisions to the minimum illumination requirements in stairwells. These recommendations for higher light levels will have an energy impact, but more importantly there is no scientific evidence that higher light levels will result in safer egress conditions. There is need for a scientific study that will inform about the appropriate lighting strategies and minimum illumination levels in stairwells.

Potential research approaches

- Testing of speed of egress and falls in stairwells under different lighting conditions. This experiment could be performed with volunteers under varying levels of smoke, noise and quantity of people.
- Lighting approaches could include mounting height of light fixtures, spacing of fixtures, wayfinding versus lighting of surfaces, effect of stair tread reflectance or contrast of stair tread to stair riser etc.

b. Fundamental research question – Is more light the solution for a safer environment?

When the 2005 Title 24 outdoor lighting standards were developed the minimum outdoor lighting requirements were set partially to satisfy security and safety needs at night time. There has been a long held perception among some law enforcement agencies, citizens groups and businesses that the way to make facilities secure at night is to over light the building façade and areas around the buildings. On the other hand some lighting researchers argue that it is better to have lower illumination levels on occupancy controls in order to enhance security and safety. Currently, there is no national standard on minimum illumination levels for safety and security.

Potential research approaches

- Correlation of lighting and crime – with other variables accounted for.
- Interviews with criminals about lighting conditions and opportunities for assault or burglary.
- Interviews with police on lighting conditions and ability of victims to give accurate physical descriptions.

5.1.3 Nighttime Adaptation and Visibility

a. Fundamental research question - What level of illumination (or luminance) is needed for acceptable levels of functioning under nighttime conditions?

Human beings can "see" under an enormous range of visual conditions, from starlight at less than .01 fc, to full sunlight at 10,000 fc. At the lowest levels of light the eye loses some visual acuity and the ability to perceive colors. The question arises what level of illumination (or luminance) is needed for acceptable levels of functioning under nighttime conditions? By whom? When? Where? For what tasks? This is a subject of much disagreement within the lighting industry.

It has long been recognized that visual performance at night is a function of the adaptation level of the eye. When the retinal cells are adapted to high light levels, as when a person exits from a brightly lit room to the darker night outside, the retinal cells are less responsive to low levels of light, and perception is inhibited. After a period of restoration, which may last from a few seconds or up to 40 minutes, the eye adjusts to lower sensitivity and can eventually see more detail in the darkness. Likewise, bright light sources within a darker field of view can temporarily bleach some retinal cells, thus lowering visual acuity for that part of the retina. The speed of restoration, and the degree of visual acuity achieved in the darkness are a function of the age, health and visual acuity of the observer, the intensity and duration of the previous light exposure, and the transitional conditions. The need for visual acuity is a function of the task being performed. Conspicuity, which describes how noticeable (i.e. conspicuous) something is, adds the additional dimension of how our brain processes visual information into meaningful imagery.

A system of nighttime lighting that promoted optimal visual function at low light levels, by minimizing glare sources and providing appropriate transitional conditions between brighter and darker areas, could conceivably both increase visibility at night and significantly reduce energy use.

Potential research approaches

- Research of gas station canopy lighting rated in terms of speed and accuracy of filling gas, and looking under the hood, and avoiding objects after leaving canopy

b. Fundamental research question – Can we develop a comprehensive predictive methodology for nighttime visibility?

This understanding was largely the motivation behind a meeting that was held in 2002 among a group of outdoor lighting experts to explore alternative approaches to setting outdoor lighting standards. One of the outcomes of this meeting, partially sponsored by the Commission, was an interest in exploring new methodologies to predict visual acuity under outdoor nighttime lighting conditions. One method proposed, termed "ETAL" or Evaluation of Task Adaptation Luminance, hypothesized that visual acuity at low light levels could be predicted based on spatial frequency analysis of a digital image of the field of view. A subsequent pilot experiment, conducted at the University of Colorado, suggests that a more complex array of factors may be involved.

There is growing interest in the lighting community to develop new digital image processing techniques that will allow illumination standards to be developed based on vision science rather than the consensus processes, based on the individual experience of professional society committee members, which has been largely used to date. While pieces of this scientific understanding exist in a variety of disparate disciplines, they have not yet been synthesized into a predictive tool. In order to reach this goal, there will need to be considerable development (and adoption) of new analysis tools and potentially also some more basic research into human visual response at low light levels.

Potential research approaches

- Computer model of night time visibility
- Validate computer model in nighttime roadway experiment

5.1.4 Glare Perception and Glare Rating

There are some in the lighting world who believe that we already understand all that is needed to be understood about glare. However, the work that has been performed on glare has as its basis a few highly constrained situations. As a result, the visual comfort probabilities used by lighting designers only partially capture how effective lighting is at reducing discomfort glare. Many designers have little guidance besides keeping the ratio of luminance of the task and the far surround to less than 1:10.

a. Fundamental research question – Can we develop a comprehensive model for measuring and rating glare from windows?

With windows, this ratio is almost impossible to meet yet there are many visually comfortable windows. Ideally a glare model would be developed that would differentiate between glarey, highlighting, OK for extended work periods, outstanding for extended work periods and boring.

This model would differentiate between various applications and lighting conditions. Prior research has already identified that the other aspects of windows (connection to the outside, visual interest, distant views etc) render windows less of a perceived glare source than other objects of equal luminance.

Finally the glare model would be compatible with lighting software so that designers can predict and compare design options in advance of building the space.

Potential research approaches

- Laboratory or epidemiological (survey) study of glare perception from windows under different lighting conditions to develop a glare rating scheme
- Computer model of glare rating

5.2 MATERIALS RESEARCH

A number of lighting technologies including fluorescents and CFLs are reaching maturity in terms of product development and market acceptance, but there is still a lot of scope to improve product performance and features. Newer technologies such as LEDs are leading the charge with the promise of much higher efficacies than the technologies prevalent today. There exists a need for PIER to fund such product development research in order to shorten the product development cycles for some of the promising technologies.

5.2.1 High reflectivity materials for luminaires

Higher reflectivity surfaces can increase the optical efficacy of light fixtures. Recent work performed by the 3M Company on large bi-refringent optics, use the difference in indices of refraction in plastic materials to make near perfect reflectors (reflectance of 99%).

a. Fundamental research question – How long-lived is the high reflectivity of materials when exposed to daylight? When exposed to electric light?

b. Fundamental research question – Are their other materials that have the same properties?

c. Fundamental research question – Can these reflectors be used to create semi-specular reflections at the same high reflectivities?

5.2.2 High efficacy sources with low toxicity

Fluorescent lighting yields high color rendering, high luminous efficacy, and long lamp life in a single product. However, fluorescent lamps contain toxic materials. Efforts have been made to vastly reduce the lead content in lamp ends and to cut the mercury content in half. But in the end the fluorescent lamp is based on the excitation of mercury gas and thus so far it is impossible to make the mercury free fluorescent lamp. Metal halide lamps also contain mercury gas.

Supporters of fluorescent technology rightly point out that the high efficacy of fluorescent lamps reduces power plant emissions. If fluorescent lamps were replaced with incandescent lamps of an equal lumen output, the additional electricity consumption would result in a greater net release of mercury into the environment. However this argument in based on the relatively high levels of mercury emitted from currently operating coal fired plants.

Mercury is powerful bioaccumulative neurotoxin. Thus there will be ongoing pressure to reduce or replace mercury in consumer products. Similar efforts are underway to remove mercury from power plant emissions.

a. Fundamental research question – Can we develop a high efficacy light source that is non-mercury based?

There are several paths that can be followed to provide high efficacy light from a non-mercury based source.

Potential approaches

- One method is to find another element that has a similar band gap to that of mercury so that light with similar frequencies is generated by exciting the electrons in that gas. In fluorescent lamps, UV light is generated by exciting the mercury gas. The phosphor coating of the lamp absorbs the UV light and “fluoresces” – emitting the light at a lower frequency. This emitted light is of various colors which combine to produce white light.
- Another method is to develop other discharge lamp gases which directly produce light and do not need phosphors.
- Finally solid state sources can produce visible light directly or produce UV light. The UV light can then excite a phosphor similar to that in a fluorescent lamp.

LED materials also have to be screened for their toxicity relative to their lumen hour production of light.

5.2.3 LED source efficacy

LED source efficacy continues to develop rapidly and various industry groups are claiming that white light LEDs should reach source efficacies 2-3 times higher than CFLs within the next couple of years. One of the PIER LRP projects developed a novel LED task lighting fixture that claims to provide ~35 lumens per watt at source. There are a number of other manufacturers, universities, and research institutes that are developing newer materials for LED such as OLEDs or organic LEDs. Manufacturers are also developing higher wattage LEDs that provide greater light output from a single LED. There are also claims of very long operational hours (in excess of 40,000 hours) form many manufacturers.

The very nature of LED industry encourages competing approaches to achieve similar results for performance, and it is perhaps not appropriate to encourage one approach over the other. However, there needs to be research into standardized methods for evaluating the performance of these technologies.

a. Fundamental research question – What materials and production processes provide the optimal combination of efficacy, light quality, cost, toxicity etc for LEDs?

b. Fundamental research question – What is the lumen depreciation of the LEDs?

Potential research approaches

- Develop industry consensus on LED performance metrics
- Independent testing of manufacturer claims of quantum efficacies

5.2.4 LED lens/luminaire efficacy

Though the theoretical quantum efficiency of LEDs can be quite high, the actual efficacy of the LED is much lower due to losses in the power supply, losses in the diode itself and its lens and reflectors. Additional research on all the sources of light loss in LEDs will complement the research on improving the quantum efficiency of the light emitting diode material.

a. Fundamental research question – What methods or materials can be used to improve the luminaire efficacy of LEDs?

Potential research approaches

- Develop luminaire designs with better (lesser) light/heat ratio for LED sources
- Develop industry consensus on LED luminaire efficacy metrics

5.2.5 Photocontrols for sidelighting

The current research on the self-commissioning photocontrol has been based on the concept of a single level of control for a dimming system. However, in sidelit spaces, the amount of daylight drops off as one moves away from the window. As a result, a daylighting control that is optimizing energy savings should be zoned so that lights are dimmed in proportion to the amount of daylight measured by the sensor and the proximity to the window. This allows control also increase the illuminance uniformity in the space.

The basis of photocontrol design has been to reduce electric lighting in proportion to the amount of daylight available so the illuminance in the space never falls below the design illuminance. However, this fundamental assumption has never been systematically verified with a large sample of users. An equally plausible criterion supported by the concept of adaptation would decrease the electric lighting less than the amount of daylight entering the space so that visibility is maintained relative to the level of adaptation to daylight. Such a lighting design might also lower the nighttime illuminance levels in an indoor space. The results of such research might provide guidance on energy effective lighting that optimizes energy efficiency and occupant productivity.